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ABSTRACT

This publication updates the 1982 occasional paper that was intended to foster staff awareness and assist colleges in Great Britain considering the use of computer-aided design (CAD) material in engineering courses. The paper begins by defining CAD and its place in the Integrated Business System with a brief discussion of the effect of CAD on the role of the designer. A general account follows of the hardware used in CAD installations with some suggestions concerning its maintenance and running. Since drafting systems are so widely available, a separate section discusses them and problems that the teaching of computer-aided drafting presents. Since comparatively cheap three-dimensional modelling systems have only recently become available, a detailed description of two commonly used larger systems is included. The next four sections are specific to particular disciplines. Some analytic modelling systems in mechanical engineering are discussed. The sections on CAD in electrical/electronic engineering and in construction engineering review commercial systems now available. Another section discusses the peculiar problems that CAD in art and design presents; some possible solutions are advanced. The final section describes a systematic procedure for selection of a suitable system. Appendixes discuss curricular issues with some suggestions for course design and list hardware and software suppliers in Great Britain. (YLB)

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COMPUTER-AIDED DESIGN IN FURTHER EDUCATION

Editor: Dr Peter Ingham, Birmingham Polytechnic

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FOREWORD

The 1982 FEU publication *Computer Aided Design in Further Education* by Peter Ingham provided a useful introduction to CAD at a time when few colleges possessed computers capable of sustaining CAD packages and when CAD was thought to be prohibitively expensive for use in FE colleges.

Since its publication there have been significant advances in computer technology, in both hardware and software, and viable systems are available at relatively low cost. CAD software packages range from inexpensive draughting aids which can be used on personal computers, to complete multi-station systems integrating CAD, CAM, production control and a range of other industrial functions. Systems which provide a reasonable semblance of industrial practice are now within reach of all but the smallest college budgets.

A limitation of the previous edition of *Computer Aided Design in FE* was that it was (deliberately) confined to mechanical engineering, as it was in this field that most of the pioneering work in FE was carried out. However there has been a rapid development of interest from lecturers in other disciplines, and specialists from the electrical/electronic engineering, construction and art and design fields have contributed chapters to this revised edition.

Finally, it must be acknowledged that this is a fast-developing area of technology, both in industry and in education. The acronyms of CAD/CAM have been overtaken by CAE (Computer Aided Engineering), often called CIM (Computer Integrated Manufacture). More recently the emphasis has been on developments in AMT (Advanced Manufacturing Technology), which attempts to integrate more closely the design and production processes. This publication identifies the ground rules against which these and further developments can be judged. It remains the responsibility of the reader, however, to keep up to date with developments. This document should assist in judging their usefulness.

On behalf of FEU I would like to express thanks to the contributors to this edition of *Computer Assisted Design in FE*—Myfanwy Trueman, Gordon Kelly, Derek Wilson and the editor, Peter Ingham, for providing their expertise in such a readable manner.

JACK MANSELL
Formerly Chief Officer
Further Education Unit

EDITOR'S PREFACE

i. In 1982, the FEU published the occasional paper *Computer Aided Design in FE* which was intended to foster staff awareness and assist colleges that were considering including CAD material in engineering courses. Since then there have been many developments in the field, the most important to FE being the emergence of modestly priced, realistic systems running on microcomputers. Students in most engineering departments now have access to computer aided draughting systems; BTEC has produced standard units in CAD, CAM and CAE, and most lecturers have a general awareness of the benefits of computer aided systems in both education and industry. There are, however, other developments that will be important in FE. Many of the firms that entered the CAD field with draughting systems are now introducing further sub-systems such as three-dimensional modellers; there is a move, particularly in larger firms, towards integrating CAD with CAM and other engineering sub-systems; and there is plenty of evidence to suggest that future CAD systems will incorporate artificial intelligence.

ii. It was considered time to update the 1982 publication in order to take account of these changes. A deliberate limitation of the previous version was that, in the main, it was confined to CAD in mechanical engineering. This paper contains sections on CAD in electrical/electronic engineering, construction engineering and art and design, all of which should increase its range of interest.

iii. The paper starts by defining CAD and its place in the Integrated Business System with a brief discussion of the effect of CAD on the role of the designer. There follows a general account of the hardware used in CAD installations with some suggestions concerning its maintenance and running. Since draughting systems are so widely available, a separate section is devoted to them. The teaching of computer aided draughting presents some problems which are discussed. Since it is only recently that comparatively cheap three-dimensional modelling systems are becoming available, a reasonably detailed description of two commonly used larger systems is included. This should help FE staff to choose a system from the many smaller ones that will appear over the next year or so.

iv. The next four sections are specific to particular disciplines. Some analytic modelling systems in mechanical engineering are discussed; most of these are cheap and especially suitable for educational use. Although CAD has been established in electrical/electronic engineering for a long time, it is only recently that it has been used in FE. Again, this is due to the appearance of micro-based systems. The section on CAD in electrical/electronic engineering reviews the commercial systems which are now available and also some which will be of interest to colleges wishing to enter the field in a modest way. The section on CAD in construction engineering is written with the same intention. CAD in art and design presents peculiar difficulties, not least because of the diverse nature of the various applications required. These problems are discussed and some possible solutions advanced.

v. Often, colleges find it hard to select a suitable system for their needs; a section has been included which describes a systematic selection procedure. Finally, curricular issues are discussed with some suggestions for course design.

vi. I wish to thank the following for permission to publish the diagrams listed:

- Graham Francis for the drawings of the robot in Section Four
- Pafec Ltd. for the drawings using BOXER in Section Four
- Deltacam Systems for the drawings using DUCT in Section Four
- Prime (UK) for the drawings using SAMMIE in Section Five
- Mike Daniels and Tony McKinley for the output from the FEA package in Section Five
- John Startin for the output from the Rigid Couplings program in Section Five

Peter Ingham
Birmingham Polytechnic

THE CONTRIBUTORS

Peter Ingham (Chapters 5 and 9)

Peter Ingham is the Director of Engineering Design Studies at Birmingham Polytechnic. He worked as a designer in the aircraft and car industries in both mechanical and electrical fields and has been involved with computer applications in engineering for over twenty years. He taught for some years in FE before taking a post at Birmingham Polytechnic to teach Computer System Programming; he now works in the Department of Mechanical and Production Engineering.

Derek Wilson (Chapter 6)

Professor Wilson is Head of Engineering and Systems Technology at the Polytechnic of Central London. His research interests are in the application of advanced computing techniques to control and signal processing systems. He is currently a Royal Society Industrial Fellow on secondment to IBM. He is a member of the IEEE UKRI Section Committee, IERE Automatic Control, Vice-Chairman, EUROMICRO, Electronic Systems Editorial Board and Section Editor, Research Studies Press.

Gordon Kelly (Chapter 7)

Gordon Kelly is Director of Quantity Surveying Studies at Birmingham Polytechnic. He practised as a Chartered Quantity Surveyor and has a long-standing involvement in the application of computing to the built environment professions. His research interests are in the use of databases and expert systems for surveyors, builders and architects. He has recently been responsible for the development of a CAD laboratory in the Department of Construction and Surveying, Birmingham Polytechnic.

Myfanwy Trueman (Chapter 8)

Myfanwy Trueman qualified as a graphic designer at Brighton Polytechnic and subsequently took a Masters Degree in Environmental Resource Management at Salford University. She spent some years directing a BTEC course in display and exhibition design at Leeds College of Art and is currently doing full-time research at Manchester Polytechnic Institute of Advanced Studies into CAD and its impact on the design process in art and design education. She has recently completed a feasibility study for the FEU into the nature of a possible national CAD Advisory Centre for art and design education and is also setting up a PICKUP CAD training scheme for a group of colleges in Yorkshire.

1. INTRODUCTION

What is CAD?

1. In broad terms, CAD is a system which uses computers interactively to assist in the solution of design problems. The design process may be separated into synthesis and analysis activities. Computers have long been used to assist in analysis; for instance, pressure vessels have been designed by computer for nearly twenty years and Joseph Lucas Ltd. had a suite of programs for alternator design in the sixties. Programs at the time were run normally in 'Batch Mode', data and programs being fed to the computer, run, and some time later answers being delivered on a print-out. If the answers were unsatisfactory then the process was repeated, the user having no contact with the program as it was running. This was an ideal way of using computers when they were a rare and costly resource but was extremely wasteful of time and human effort. Because product life cycle times have now dramatically decreased, it is essential, if a firm is to remain competitive, that the design iteration time should be as short as possible within the constraints of design quality. Thus, the degree of utilisation of computers is not as critical as it was formerly and the method of using them has changed. Computers are often used interactively, the user having intimate contact with the program as it runs by means of a terminal or workstation. Not only does this make sound economic sense, it also permits a far more creative use of the machine. Tasks may be allocated so that human and machine are each doing what they do best: the human making decisions based on experience, expertise and imagination, the machine performing rapid, repetitive calculations and accessing bulk data quickly and precisely. More recently, computer systems are making inroads into the more creative aspects of design. For instance, in mechanical engineering and architecture, systems are being used to view products or buildings to help in decisions about aesthetic appeal. It is highly likely that in the future, CAD systems will be used extensively in design synthesis.

2. CAD is a useful tool if used in isolation from other engineering functions and merely as a means of displaying graphical data but it also provides a potential for making effective links between the other sub-systems which exist in a manufacturing concern. It is a prime means of setting up and accessing a product database which may be used, for example, by the manufacturing processes also. With the current move towards the integrated business system, where design, production, finance and marketing form parts of a cohesive system, CAD offers benefits beyond productivity increase.

3. It is necessary for designers to communicate their ideas, usually graphically, to other interested parties in a firm. Designs submitted to customers for approval must be costed, must be planned for production and so on. In mechanical engineering, the most common means of formal communication is the two-dimensional orthogonally projected drawing which has traditionally been the major repository of product information. Many experts consider that this is an inadequate notation for today's purposes and that conventional drawing will be replaced by three-dimensional modelling eventually. The most obvious reason for this is that, very often, a component is not defined fully dimensionally—'blend to suit' is a common note on drawings—and sometimes, even more insidiously, drawings overdefine a component. Occasionally, the orthogonally projected drawing is an ambiguous representation of a component. Also, two-dimensional views of a component are often unsuitable for passing to analysis programs, for instance, to calculate the volume, position of centroid and moments of inertia. The three-dimensional model is clearly of a higher order than the traditional drawing since an orthogonally projected two-dimensional drawing can be easily obtained from a three-dimensional model while, generally, the reverse is not true. In electrical/electronic CAD, an analogue of the three-dimensional modeller is the hardware description language (HDL). HDLs will be described in Section Six.

What benefits can be obtained from CAD?

4. The benefits of CAD are often quoted as some or all of the items in the following list:

- improved productivity, shorter lead times or fewer personnel
- faster responses to quotations
- forced standardisation
- improved design accuracy
- forced exact definition of products
- faster and more controlled modifications
- better communication between engineering and other personnel

Most books on CAD have even longer lists of claimed potential benefits than this.

5. Firms may not necessarily commit themselves to CAD just for technical reasons but also because they wish to project a progressive corporate image. Others may be suppliers to large firms who insist that drawings are provided as files which may be input to a CAD system. Usually, though, the explicit reason for entering the CAD field has been the desire for a productivity increase which is variously quoted as a factor of 3-10 or even higher when CAD is used as part of an integral CAD/CAM system. It is agreed widely now that the most clearcut benefits of CAD are not directly to do with productivity; they result from improvements in design

procedures, improvements in control of design management and improved communication between the design database and other functions.

6. In education, these benefits do not, of course, apply. We must supply CAD training because there is an increased demand for it; but there are other reasons why it is useful to include it in curricula. The most tangible is that CAD has introduced a degree of discipline into the teaching of design which has often simply played a nebulous integrative role. Unfortunately, the current tendency is to separate CAD from conventional design and treat them as different subjects. It is to be hoped that this is merely a temporary distinction: properly, CAD should be subsumed into design.

The effect of CAD on the designer

7. It sometimes seems that there are as many books about design as there are designers. In the first chapter of most of them, the author identifies the stages of design as some variation of:

- statement of need
- specification
- conception of solutions
- evaluation and selection
- analysis

There is a good deal of controversy about the nature of design but it is convenient, when computers are used to aid the design process, to take this simplistic view. This enables tasks to be allocated in a well-defined way between human and machine; computers work procedurally and systems are currently tightly constrained by computer operation. A difficulty with this approach is that the model may not match, even crudely, an individual's personal method of working. Many designers operate in a highly imaginative and idiosyncratic way and find CAD systems irritating and restricting to use. Research is being carried out into 'adaptive interfaces' where the system will be presented to users in a way which more closely suits their individual method of working. It is commonly experienced that as users become accustomed to a system, their method of operation changes; some systems (e.g. PAFEC DOGS) recognise this by permitting the user to switch between 'novice' and 'expert' prompts, the former being more verbose and helpful but extremely irritating to the skilled user. It is anticipated that future systems will adapt automatically to suit users' preferences. In particular, adaptive interfaces will permit designers to use CAD systems in a natural and individualistic way.

8. There is a lot of activity currently in applying the techniques of artificial intelligence (AI) to CAD systems. In many design tasks (for instance, material selection), the expertise involved is largely of a definable nature. Expert Systems are programs for eliciting this type of expertise from experienced practitioners and creating a 'knowledge base' so that a comparatively inexperienced user can perform the task satisfactorily. Some Expert Systems permit rather more *probabilistic* expertise to be elicited so that more subjective judgments can be made. It is unlikely that a completely unskilled person could have the system awareness or confidence to perform any significant design function with the current Expert Systems, but the field is rapidly developing and it is likely that AI will lead to fundamental changes in designers' methods of working in the future. Engineers, in general, should become gradually less specialised and much broader in their expertise. This should be reflected in our courses which it may be necessary to modify fundamentally. It is one of the stranger effects of the newer technologies, that in many cases they introduce an element of historical circularity and it is possible that future engineers will resemble the apocryphal 'all-round' engineers of the past.

2. CAE HARDWARE

Computer configurations

9. A graphics system comprises a processor and input/output devices. A graphics screen and some means of communicating with it interactively are usually called a 'workstation'. There are many configurations used and any combination chosen from the following (non-exhaustive) list is possible:

Processor:
- large mainframe
- minicomputer
- microcomputer

Input devices:
- light pen
- graphics tablet
- tracker ball
- thumb wheels
- joystick
- joydisk
- mouse
- QWERTY keyboard
- function keyboard

Output devices:
- alphanumeric screen
- graphics display terminal
- hard copy unit
- pen plotter
- electrostatic plotter
- digital readout

10. A typical graphics workstation used in education has a graphics display which is used for showing both alphanumeric information and pictures. Probably the commonest way of interacting with the graphics system is by positioning and pointing to objects on the screen with a crosshair cursor following the movement of a puck on a graphics tablet, with function buttons used to input the desired position. Co-ordinates, text and possibly commands are input on a conventional keyboard. Commands are either input by pointing with the cursor to items on an on-screen menu, or input by pointing to dedicated areas of a menu card taped to a graphics tablet. Graphical output is displayed on a screen which is used as a sort of sketchpad; drawings can be examined in detail by zooming in on selected areas and so very high resolution screens are not essential. For permanent records, the screen image can be dumped to a hard copy unit which is adequate for most student use, or the drawing may be plotted on a pen plotter which gives better quality but takes longer and ties up the computer.

11. Many workstations can share one large processor, each user having the impression of being the sole user; this is a common configuration for industrial installations. In this case, the central computer will have bulk storage—probably both disk and tape storage; programs and drawings are stored on the disk and archived to magnetic tape, usually with a system for long-term storage and retrieval of drawings. Output devices may also be shared among users, plotters and hardcopy units being examples.

12. At the other extreme, workstations may be 'stand-alone', each workstation having its own processor—often these days, a microprocessor. Although it is not immediately obvious, graphics work requires a lot of calculation and, in order to improve response time, many well-known systems are supplied with a second processor to speed up the arithmetic. If the work is at all serious, some bulk storage device, for instance a hard disk, should also be included in the system. Currently, many systems are based on microcomputers such as the IBM. There are other options intermediate between the centralised time-shared system and the dedicated microcomputer; a central processor can be used to handle databases while workstations can have sufficient local processing capability to perform graphical operations. The central processor may also be used to perform 'number crunching' jobs such as finite element analysis or solid modelling.

13. Networked systems are becoming common in industry. In a network, two or more separate computers are linked together by some form of communication system. The advantages of this arrangement apply particularly to CAD installations; it introduces the possibility of easy expansion of the system and computer power can be shared, but most of all, it allows the separate sub-systems to communicate with each other and so provides a better flow of information. There are various types of network; the one most likely to be used in a college is the LAN or Local Area Network where the separate processors are close together and often located on one site. Some colleges have installed LANs with varying degrees of success. LANs now appear to be reliable enough but the advantages of using them for CAD/CAM work are marginal in most educational situations. One could perhaps make a plausible case for their use when geographically separate CAD and CAM systems exist.

14. Some of the more widely used hardware components will be described in the sections which follow. Because of the wide range of equipment, this is not an exhaustive account, but more information may be obtained from manufacturers who are generally very helpful and willing to provide data about their products.

Screens

15. There are many types of graphics display – possibly as many as twenty. However, the most commonly used in CAD work are: Refresh Tubes, Direct View Storage Tubes (DVST) and Raster Tubes. Of these, Refresh Tubes are not common in colleges except in highly specialised circumstances. They will therefore be ignored in the following account.

Direct view storage tubes

16. The DVST was first developed by Tektronix in the seventies and held sway for several years. It is an example of a 'calligraphic screen'; the picture is drawn directly onto the screen phospor by deflection of the electron beam. The picture need not be refreshed at a high rate to prevent flicker since a system of 'flood guns' maintains it on the screen indefinitely after the first drawing. Since the image is not refreshed, there is no top limit (beyond the intelligibility of the drawing and the screen resolution) on the picture detail. Typically, DVSTs are addressable to 4096 x 4096. Thus, a highly detailed picture can be displayed, making them suitable for work such as very large scale integration (VLSI) design.

17. Because of the screen technology, selective erasure is impossible—this means that even a small change in the picture requires a total re-draw, which occurs with a rather offensive green flash as the flood guns are turned off. The storage tube is therefore not suitable for real-time animation. Because an image may be held continuously on the screen, most sytems automatically dim it after a fixed period so that it is not burned permanently into the screen phosphor.

18. Some of the more costly storage tubes have local storage facilities and parts of drawings can be stored in the graphics system. They also have a limited refresh facility, often in a colour different from the storage tube image. However, no coloured, shaded imaging is possible with DVSTs.

Raster tubes

19. These are the graphics workhorses, almost always found in academic installations. On raster-scan tubes, the electron beam scans the whole screen in a prescribed pattern. At defined intervals the beam is modulated so that an image is drawn in an array of dots or picture elements (pixels). The complete raster pattern must be redrawn at a 'flicker-free refresh rate' which is usually 50-60Hz. Pixels can be lit at different intensities, giving a 'grey-scale' capability; or colour can be provided reasonably economically.

20. There is a great difference between the usual colour monitor used with small microprocessors and colour graphics terminals—the cost of the latter differs from that of the former by a factor of one hundred in some cases. The reason for the disparity in cost is image quality and the capability of performing local graphics processing. There is a steady move towards this type of distributed processing. Although the cost of graphics displays is not dropping as dramatically now as it once did, more sophistication is usually provided for the same money. For instance, an expensive screen, the Lexidata Solidview, has been specifically designed for solid modelling and performs a lot of the processing needed to render solid models realistically. This type of display is termed a 'smart' display as opposed to the cheapest 'dumb' terminals. Some of the facilities of a common mid-price terminal, the Tektronix 4107 Colour Display, will be described in more detail.

21. The terminal has a 3-inch display, a 60 Hz refresh rate, addressability of 0-4095 in both x and y directions, and a resolution of 640 x 480 pixels. The terminal can be considered to be two separate displays in one package since graphics and alphanumeric data can be displayed independently; a scrollable dialogue area of an adjustable number of lines is used to display text in any one of eight alternative character sets. Up to 16 colours can be displayed simultaneously in the graphics area and eight colours in the dialogue area, colours being chosen from a palette of 64 distinct colour mixtures. Addressability is higher than resolution, which permits a hardware zoom and pan facility to be provided so that selected portions of a picture may be examined in detail using hardware only. Cursor movement may be controlled either by a 'joystick' —tiltable disk which acts much like a joystick—or by a graphics tablet and puck. The keyboard has eight programmable function keys like many common microcomputers.

22. The screen's graphics facilities include the ability to draw lines in various linestyles in colour, to block-fill bounded areas with solid colours, or a range of textures. Graphics text can be added to pictures in different sizes, colours and rotation angles, and text founts can be user-defined. Groups of graphics objects can be defined as 'segments' and can then be stored, redisplayed and manipulated as single entities. Individual pixels can be written in colour, portions of displays may be blinked on and off, and eleven standard markers may be used to show, for instance, data points on graphs.

23. This is just a selection of the facilities available on this display; these can be used under program control to perform some of the simpler graphics processes very rapidly, thus speeding up display processing and taking some of the load off the computer.

24. Various other kinds of display are available, including:

- plasma panels;
- vibrating mirrors;
- laser scan.

It seems that, at the moment, raster technology is well established, but it is fairly certain that in the research and developement department of some display firm there is work being carried out on an unconventional display which will revolutionise graphics tubes in much the same way as did the Direct View Storage Tube in the mid-seventies. It is highly likely that soon, full-colour, shaded images capable of animation in real time will be produced.

Plotters

25. Small plotters are very cheap today and one can purchase an A3 or A4 plotter for less money than many microprocessors. Many of these, though, are of flimsy construction and unsuitable for use with students. Plotting in an educational environment is more demanding on equipment than in industry; it pays to obtain the most robust plotter that can be afforded. Often suppliers recommend a plotter with the sytem that they are supplying. Most CAD systems, however, support various plotters. These are listed in the configuration program. Often money can be saved by configuring the system with a plotter that you already have.

26. Pen plotting should be strictly rationed, not just because of the wear and tear on the plotter, but also because of the high cost of special paper and pens. In an industrial environment, drawings often go out to customers and so great care is taken to ensure that the quality of the plot projects the right corporate image. Plotting is usually done by wet ink pens and many firms go to great lengths to find a suitable combination of pen, ink and paper. With wet ink plotting, the pens are usually of the familiar stylus type and because of the irritating tendency of the ink to stop flowing, it is usual to waste many plots. In colleges, fibre pens are a better prospect but these are costly. However, it is economical (and easy) to convert used pen casings to holders for cheap fibre tip refills which work satisfactorily. Again, many manufacturers recommend their own 'high-quality lint-free' paper which also costs much more than one would expect. It is not at all necessary to buy this; use of good quality typing paper, guillotined to suit if needed, will reduce the plotter paper bill.

Hard copy units (screen dumps)

27. These are normally dot-matrix printers or specialised electrostatic units. In either case, they operate by transferring the picture on the screen directly to the printer and so do not make any demands on the processor. Electrostatic devices are more expensive but operate faster. Both types are economic to use, the dot-matrix type requiring

only listing paper and an occasional ribbon, while the electronic unit needs cheap rolls of paper and toner. Since hard copy units can serve several workstations, since they take up no processing time and since their running costs are low, they are ideal for educational use.

Maintenance and repairs

28. A maintenance contract on computer equipment costs usually in the range of 10% to 12% of the purchase price per annum. In education, this may represent an impossible continual outlay. Many colleges do not pay maintenance, but use the 'fire-engine' approach, paying for time and parts when required. Since nobody in education ever has sufficent workstations, it is a minor disaster if one is out of action until the cash is available to pay for repairs. One solution is DIY maintenance. The larger vendors of equipment provide in-house courses in maintenance and repair at various levels. These courses are not cheap but considerable savings in time and cash can be effected if technicians are trained to detect faults and perform repairs at the board level on some of the more widely used equipment. Screens, for instance, are often of modular design and defects occur commonly on particular boards—notoriously, the power supply board is prone to develop faults. If a small supply of these fault-prone boards is purchased, then 90% of the repair work can be done by replacing boards; often firms offer a rectification service for faulty boards which is usually fairly cheap but slow. Of course, if technicians are electronics specialists, then they may be able to find and rectify faults at the component level, which is even cheaper. If several colleges in a region have similar equipment, then it may be beneficial to perform this type of rudimentary repair on a co-operative cost-sharing basis. It is important to have some maintenance strategy since most CAD courses are highly practical in nature and will suffer drastically if the equipment is not working. Most hardware manuals contain routine maintainence procedures. These should be examined and a set of instructions drawn up for the CAD technician to follow regularly.

3. DRAUGHTING SYSTEMS

Introduction

29. Although computer-aided draughting systems are only part of CAD and some experts consider that conventional two-dimensional drawing will disappear completely during the 1990s, most firms (and colleges) use them as an entry point into CAD. The reason for this is that they are easy to understand and their potential for improving draughting productivity seems obvious.

30. Current draughting systems are based on a wide range of computers from large mainframes through dedicated superminis down to modest microcomputers. In general, the systems based on larger machines are superior in that they have more sophisticated facilities although there are now many highly respectable and useful systems based on micro-computers. Also, more development work has been done on the drawing procedures in larger systems so that they may be used in a more flexible and natural way.

31. Most draughting systems are driven by a combination of menus and keyboard input. Menus may be displayed on the graphics screen or may be drawn on cards taped to a bit-pad or small digitiser. On-screen menus are often 'picked' by moving a cross-hair cursor around the screen matching the movement of a stylus or puck on a bit-pad, although it might be argued that a mouse would be cheaper and just as effective. In theory, the bit-pad can be used for digitising existing drawings but this is not normally done on such a small pad with its inherent low resolution. Systems exist which use touch-sensitive screens but it is tiring to spend long periods of time holding up an arm. Each of these methods has its own protagonist but no system, even the dearest, seems to be satisfactory for all users. Often, systems permit users to type in commands as an alternative to picking from a menu and experienced users tend to use a combination of both methods.

32. Menu-driven systems can be designed in several ways. In PAFEC DOGS, the whole menu is displayed on one screen. Because of the need to keep the menu small so that as much of the screen as possible is available for drawing, a menu option is selected by two picks—one for main menu item, one for sub-menu item. For example, in order to draw a circular arc, one picks first 'LINE', then '4' which is 'clockwise circular arc'. This system is effective for trained users but in order to work speedily, one needs to memorise at least a subset of the 250 or so options. AutoDesk's AUTOCAD uses 'pull-down' menus where a comparatively simple root-menu is initially displayed and the selection of an item results in a sub-menu being written to the screen, the

process being continued if necessary. This tree-like system requires very little effort of memory but tends to be irritating after a time because of the delay involved and because the continual screen changes are tiring to the eyes. The designers of AUTOCAD have recognised this and users can type in commands as an alternative to using menus. Another advantage of AUTOCAD is that it is comparatively easy to design one's own 'customised' menu structures. In systems like SUPERDRAFT, menu items are picked directly from a menu-card taped to the bit-pad, each item being allocated a separate area containing a small descriptive drawing or 'icon'. Although some of the larger commercial systems use this method, it has the disadvantage that one is constantly switching gaze from the screen to the menu card. Some systems may be configured with separate screens for alphanumeric and graphical work. Opinion is divided on the merits of this layout; it is certainly more expensive than using a single screen.

Drawing options

33. The drawing options that should be provided by any realistic system are: drawing commands to permit figures to be built up from lines and arcs in a convenient way; editing facilities such a copying, dragging, selective deletion and transformation of figures and other facilities such as hatching, automatic dimensioning, layers, text and various line types. Given a reasonably comprehensive set of drawing options, it is possible to draw any geometric form that can be constructed by manual means and to draw it more conveniently, quickly and usually in several different ways. Sometimes, the quickest technique is discovered only after a considerable time using the system and is passed on from one draughtsperson to another as a form of 'lore'. System user groups are a rich source of this kind of information. In transferring from one system to another, it is not just a matter of learning a fresh set of drawing options; the user often requires a completely different method of working demanding a good deal of 'unlearning' before a reasonable expertise can be obtained. Most small systems have idiosyncrasies which force the user to work in a way which may not come naturally. For instance, on some systems, plotting is done directly from the drawing file, lines and arcs being plotted in an order that depends on the sequence of drawing. In order to minimise plotting time, drawing must be done with an eye on plotter pen movement. On larger systems (and on some small ones, too) a separate plotfile is created from the drawing file with the express purpose of minimising pen movement. Also, the hatching and filleting procedures provided by small systems often require drawing to be done in an artificial way with a lot of manual operation and previous planning of draughting procedure.

Symbols

34. Most systems permit parts of drawings to be defined, stored and retrieved. These are usually called symbols but are occasionally given a different name—AUTOCAD calls them blocks. Examples are: machining symbols, tolerance boxes, logos, standard drawing sheets, conventional representation of machine elements and electrical component symbols. A defined symbol may be placed on a drawing at any position and usually at any angle of rotation and orientation. In DOGS, a symbol is defined, named and has up to three 'keypoints' which determine the placing of the symbol; one keypoint is used for positioning, the second governs the angle of rotation and the third, the orientation. In addition, variable text may be added, which is useful in applications such as standard drawing sheets and tolerance boxes. AUTOCAD blocks are more primitive but are still a useful facility. A good battery of symbols is a considerable help in the improvement of draughting productivity especially in the drawing of schematics. Often firms create their own set of standard symbols to suit their specialisation and it is possible to buy a set of symbols for most common fields, for instance, hydraulic and pneumatic symbols.

Parametric symbols

35. Often, manufacturers produce ranges of components which have broad geometric similarity but different dimensions. For instance, a lifting appliance firm might produce jacks differing only in bore and stroke, or a firm might produce escalators with all features common except the number of steps. These applications would be ideal as parametric symbols. The procedure for drawing them would be described in some formal way with the differences treated as variables for which the user would be prompted when the symbol was called up. The symbol is then developed interpretively from the parametric definition. It is possible on large systems, with a considerable outlay of time in programming and debugging, to produce a highly complex dimensioned drawing in this way. The process of setting up parametrics needs a different skill from that of draughting and normally requires some programming expertise. Micro-based systems usually have either elementary or no parametric facilities. There are exceptions—SUPERDRAFT provides a neat and simple table-driven parametric facility, the user setting up a table listing the variable dimensions of a range of standard items. The appropriate dimensions may then be selected as the symbol is developed. DOGS has a sophisticated parametric symbol description language with input, output, subroutines, conditionals, file I/O and BASIC-like arithmetic.

36. Parametrics are undoubtedly, in favourable circumstances, a most powerful aid to improving draughting productivity and many firms are heavily involved in parametric symboling. In extreme cases, a drawing can be produced with no operator intervention at all beyond the input of critical dimensions—although in these applications, it is sometimes questionable whether a drawing is really necessary, since a datasheet might suffice.

Attributes and properties

37. In engineering, the traditional repository of information about a manufactured part is the drawing; geometric form, material specification, machining information and amendment history are often obtainable from it. Other information such as volumetric properties, weight and cost may be obtained indirectly. It is desirable for system integration that these attributes should be attached in some way to the computer representation of the component and although a two-dimensional drawing is not an ideal vehicle for all attributes, most large systems provide a facility for linking them to the drawing. There are problems still to be overcome in this area—for example, it is little use attaching a volume attribute to a drawn component if the volume is not automatically recalculated when geometric form is modified. This is a major argument for the use of 3-D models where attributes such as volume, position of centroid and moments of inertia can be calculated directly from the geometric form and so are implicit attributes.

38. DOGS has a properties facility which is useful in the preparation of schedules. For instance, in hydraulic design, costs can be attached to different types of valves and cost/metre to different types of pipe. Subsequently, as a hydraulic system is being developed on the screen, the draughting system automatically calculates a costed bill of quantities for the different types of valve and pipe runs. This may also be done to a limited extent in AUTOCAD, where the drawing file may be processed by an external program. The latest version of AUTOCAD includes a LISP processor, which may be used for this purpose, although LISP is not a language that would be easily used by unskilled programmers.

39. In theory, it should be possible to obtain coding and classification data directly from the geometric model. Again, the most convenient model for this purpose is a 3-D representation and there is considerable research being carried out in this important field. CIMTEL Ltd. produces a micro-based coding and classification system which is suitable for educational use.

Archiving

40. When a firm installs a computer-aided draughting system, the change in draughting procedure is not the only factor to be considered. The firm must also decide whether it is going to retain the old system of drawing storage, to store drawings completely on magnetic media or a combination of the two. It is also possible to use magnetic media with a parallel microfilm system. This is an ideal time to examine the whole process of drawing storage, retrieval and amendment control. Most large systems have an integral drawing management system; most micro-based systems do not. Micro-based sub-systems for drawing office management, which may be purchased separately from the draughting system, are available. An example is CIMTEL's Drawing Office Administrator which may be used in conjunction with any draughting system. This offers a method of monitoring drawing registers, ensuring that the production, revision and issue of drawings is controlled and provides a means of monitoring the flow of work through the drawing office. In a college environment, drawing management is not usually required, but consideration of this topic should be included in all specialised courses on CAD; and it is very useful as a project.

Data exchange systems

41. Many large manufacturers buy in parts and it is common for them to insist on suppliers submitting component drawings in a form—usually mangetic tape—suitable for input to a CAD system. This is to avoid redrawing the part with consequent waste of time and likelihood of error. If the supplier has the same system, then this presents no difficulty, but usually the systems are different. Since all CAD systems have their own graphical representation format, there is a problem of data mismatch. An analogous problem also exists in construction engineering where large projects are commonly divided among sub-contractors. A possible solution would be a progam which would translate from one format to another, but this would mean that each pair of CAD systems would need two translation programs, one in each direction. A better scheme is to establish a 'neutral' or intermediate format to which graphical data from one system is preprocessed. This neutral format data can then be post-processed to give data suitable for input to another system. This is clearly more economical of programming effort. If, for instance, we were concerned with six CAD systems, direct translation would require 30 translation programs. If we used a neutral format, then only six preprocessors and six post-processors would be needed. This procedure is well established in achieving programming language portability between different computers where intermediate codes are commonly used.

42. The best known standard for neutral format is the Initial Graphics Exchange Specification (IGES). IGES format includes geometry definition (point, line, arc, etc.) and annotation (text, dimensions, etc.). Pre- and post-processors for IGES have been implemented by most CAD system vendors. Unfortunately, it only supports two-dimensional graphics and wire frame modelling (see Chapter 4) and so is not of universal application. It is likely that IGES will be replaced by another international standard, the Standard for Exchange of Product Data (STEP), which should be more widely useful and relevant to modern systems. Since data exchange systems are of such importance in CAD, they should be discussed in all specialised courses and could form the basis of some good student projects. It might also be possible to use neutral formats to attain some degree of portability in computer-based teaching packages for CAD and similar topics.

Teaching computer-aided draughting

43. It is undesirable to teach the whole of a draughting system by 'chalk and talk' means if only because it would involve the description of as many as two hundred options or more in some systems. Ideally, students should be guided through a small sub-set of the possible drawing operations and encouraged to learn the rest through practical experience. This 'black box' approach has clear advantages. If the system has satisfactory 'help' facilities which may be called on in time of distress, then students can learn to use most of the available options by a process of discovery, which engenders the 'system-wise' approach necessary if users are to be exposed to many different systems during their working lives. Of course, where equipment is limited, it may not be possible to use this method wholly but it is an enjoyable and profitable exercise to get a class to investigate, say, hatching in this way, with the lecturer writing down discoveries on the board and discussing them later. Synergetic effects are particularly pronounced in group work with computer systems and it is usually helpful for students to work in pairs. This is useful where resources are limited, but also has a beneficial effect on students.

44. Computer-aided draughting is an ideal area for student-centred learning techniques. A good package, which could be used as an exemplar for other systems, is the Sandwell College DOGS Open Tech module. In order to get most benefit from a system, there should be some open sessions in which work stations are available for casual use. Staff must be dissuaded from using the CAD room as a teaching room and students should be permitted to use any vacant seats even when a timetabled class is using the system. Since equipment is expensive and quickly obsolescent, the aim should be to use it as much as posssible—each evening if staff resouces permit. Most technically minded students are highly

motivated to use draughting systems because they are interested in them and, quite rightly, see them as a means of keeping or getting a job. This is evidenced by the commonly experienced difficulty in prising them away from the keyboard to let someone else use the system. Students should be encouraged to use the draughting system not only for technical draughting but also for such applications as loci of mechanisms and diagrams for project reports.

45. It may not be considered suitable to work in such an unstructured way and staff may prefer to present students with a series of didactic examples which are worked through and discussed afterwards. The examples should be carefully prepared—it is a waste of time for students to prepare a drawing from scratch if it is only intended as a vehicle for practice in dimensioning; partially completed drawing files should be used.

46. Even with a computer-aided draughting system, standards of drawing will vary. Students must still have instruction in good draughting practice so that their drawings are effective pieces of communication with correct dimensioning, appropriate text size and line types, proper projection and view placement and attention to British Standards. They should also have instruction in good computer-aided draughting practice, including creative use of layers and symbols, minimisation of plotter pen movement (if the system does not try to optimise it automatically), appropriate use of drag, copy rotate and mirror facilities and file storage discipline.

47. It is useful to insist on a small amount of documentation being submitted with drawings, listing any problems encountered so that some remedial instruction can be carried out. Computer-aided draughting assignments need not be just a set of engineering component drawings; some suggestions are:

i) Draw a set of lay figures from anthropometric data supplied; store them as symbols and use them to design various workstations (group assignment).
ii) Draw your own logo and store it as a symbol.
iii) Design your own draughting sheet, use your logo symbol on it and store it as a symbol.
iv) Design a set of standard electrical symbols (group assignment).
v) Draw a robot, storing each element as a symbol and produce a drawing of the robot in various positions.
vi) Design a text fount which can be used on departmental posters (group assignment).
vii) Devise a drawing office standard for: pen thickness, use of layers, text sizes, standard notes, etc., and present it in a manual (group assignment).

viii) Produce a drawing of a complex tabulation and minimise the plotting time (working competitively).

ix) Produce a coupler curve for a four bar mechanism of given dimensions.

x) Draw a layout of the college machine shop, store the plan view of each machine as a symbol and use these symbols to draw an alternative layout (group assignment).

xi) Produce a simplified map of the college which may be selectively zoomed for extra detail.

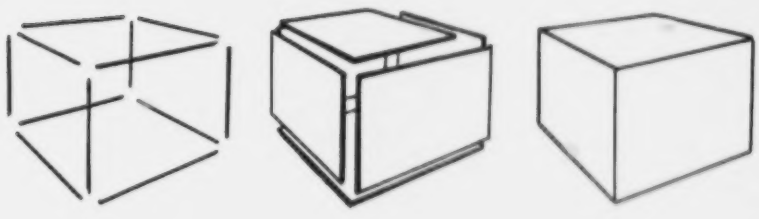
xii) Design a set of symbols representing standard aluminium windows.

4. THREE-DIMENSIONAL MODELLING

What is 3-D modelling?

48. A three-dimensional model is a mathematical representation of a body in some form suitable for computer storage and subsequent processing. There are several ways of representing a body; three used in CAD (Figure 1) are:

- Line models
- Surface models
- Solid models



Line Model *Surface Model* *Solid Model*

Figure 1

49. Line models are sometimes called 'wireframe' models. In these, a body is described by the lines which make up its edges. This representation is suitable for bodies of which all the surfaces are flat; curved bodies may be faceted in much the same way as a soccer ball is built up from flat panels. Although this is a simple way to model a body, it can, as may easily be demonstrated, give rise to ambiguous definitions. Wireframe models are useful for simple displays of uncomplicated bodies in minimal processing time but are not really suitable for anything more sophisticated. Some draughting systems have wireframe modelling facilities—PAFEC DOGS is an example.

50. Surface modellers are a considerable advance on wireframe modellers and define bodies by the surfaces, possibly curved, which bound them. These surfaces are built up from mathematically defined patches so that the co-ordinates of all the points on the surface of the body are known. An example of a surface modeller is DUCT which will be described later in this section.

6. CAD IN ELECTRONIC ENGINEERING EDUCATION

Introduction

74. Technological predictions in the late seventies, suggesting that 32-bit systems would be available by around 1985, were received sceptically in many quarters. However, the semi-conductor industry delivered its products on time and at costs which have proved to be remarkable. We now have the technology to design and manufacture complex electronic circuits reliably and to design and manufacture Application Specific Integrated Circuits (ASICs) in accordance with the demands from the market. It has been estimated that a worldwide demand exists for 1.2 billion square inches of silicon wafers per annum. Current (1986) manufacturing capacity is around 4.5 billion square inches; consequently, silicon process technology is not limiting the application of computer-aided design.

The impact of workstations

75. The rapid development of microprocessors during the early 1980s enabled very sophicated computer engineering workstations to be introduced, often using one of the 32-bit microprocessors: Motorola 68020, Intel 80386, NS 32032. CAE workstations from new companies, for instance Mentor and Daisy, competed with established suppliers such as HP, DEC and IBM. However, although new companies such as Apollo, Sun and Whitechapel have created a market with their innovatory products, the major computer manufacturers, particularly IBM, increasingly dominate the marketplace.

Circuit technology and design techniques

76. The following sections discuss the circuit technologies and design techniques now available and to which FHE curricula will need to relate.

Circuit technology

77. Surface Mounted Devices (SMDs) are being used increasingly in the production of electronic circuits. However, the range of components available in the form of leadless packages is relatively small and many PCBs will use various kinds of components, e.g. Dual-in-line (DIL) and many other circuit elements. The use of SMDs has led to the introduction of solder pastes as an alternative to the proved high production method of wave soldering which permits boards with mixed components (SMDs on the bottom and leaded components on the top) to be soldered in one pass. Solder pastes are suspensions of solder powder in a gelled, fluxed medium and can be used in a similar way to printing inks and adhesives. Once placed in position on the PCB, the solder paste will retain its shape and 'stickiness', enabling components to be

51. Solid modellers are considered by many experts to be the most advanced form. Unlike the previous two types, they take account of the solid properties of a body. There are several types of solid modeller; in one of the more common, the constructive solid geometry (CSG) modeller, bodies are built up from standard solid building blocks called 'primitives'—a set of primitives might include block, sphere, cylinder, cone and torus. An example of a CSG modeller is PAFEC BOXER which will also be described later in this section.

52. Although solid modellers may be potentially technically superior to surface modellers, in practice they do not seem so useful. They cannot model some common shapes —for instance, most cannot even model a screw-thread. The supporters of solid modelling would claim that it is unnecessary to model one—they need only to model a hole, then label it with the attribute 'tapped hole' in the same way as is normally done on conventional engineering drawings.

53. There are other difficulties in representing engineering components which have not been completely resolved—filleting and tolerances are two. Because of the comparatively free forms that can be represented with advanced surface modellers such as DUCT, these seem far more useful at the moment. However, three-dimensional modelling is still at an early stage of development; there is a lot of research activity being carried out in the field and future solid modellers may have none of these drawbacks. Many firms, particularly the larger ones, are either using, or investigating the use of, solid modellers and recently a few micro-based systems have come on to the market. They are extremely useful in design teaching, not only because they reflect industrial practice, but also because using them seems to enhance students' powers of visual perception.

Why are 3-D modellers used?

54. In CAD work, we often wish to set up a computer representation of a component for various reasons—performance analysis, costing, process planning, manufacture and so on. Traditionally, the basic representation of a component is the engineering drawing which usually contains most of the information needed for production. Thus drawings have:

- a geometric description of the part as a set of two-dimensional views. Commonly, this description is incomplete and sometimes over-defined;
- information about production and gauging requirements such as tolerances and details of split lines and draft angles;
- surface information such as machining lay and surface finish;
- material information such as specification and heat treatment.

placed and held in position prior to the melting of the solder to make the joints. The melting is achieved by either Vapourphase Reflow or Infra-red Reflow. In the former, heat is transferred by vapour condensing on the workpiece and rapidly transferring its latent heat of vapourisation to the board. In the latter, electromagnetic energy is transmitted through the material at frequencies which are matched to the absorption characteristics of the components. Quality solder connections are claimed for this method.

78. Currently, the emphasis is on fully integrated production to give completely automatic handling of boards with a variety of options. Preparation of the PCB for drilling can be fully integrated with the CAD system generating CNC drill data in a format suitable for the drilling machine and down-loaded to the production line. Drilling machines with air-bearings and spindle speeds of 100,000 rpm are available with vision sensors to detect drill breakage, etc. Consistent with the increased complexity and circuit density of PCB designs, the development of automatic test equipment (ATE) now enables test functions to be integrated with the production process so that all circuit parameters may be checked against their specifications, individually if required.

Design techniques and software tools

79. One of the most fundamental design decisions to be made is the choice between:

- an integrated circuit using a semi-custom or fully custom design facility, or
- the integration of commercially available components.

The majority of modern workstations permit either to be implemented if suitable software tools are available. Software tools are analogous to hardware tools such as spanners and screwdrivers—they can be used to design a variety of circuits with a wide range of applications. They are a result of the development of workstations and the move away from mainframes with their specialised programs generally providing specific answers to specific questions. Current software tools enable the engineer to design application specific circuits, subsequently integrating these in PCB layouts with other standard components such as memories.

80. A major problem has been the compatibility of different software tools when results from one are needed as inputs to another. Specialised software vendors now provide an integrated range of facilities; an example is Lattice Logic's tools for the generation of ASICs:

- MODEL: a hardware description language (HDL) designed to describe structures of connected objects and providing a clear and unequivocal description of components.

A lot of other information about a part is scattered around a firm, often on pieces of paper in filing cabinets and it would be better to centralise as much of this information as possible. The advantages are clear—for instance, access is easier and more closely controlled and amendments may be associative. This centralised source of information may be regarded as a model of the component and may be refined to any degree which is considered economic or convenient.

55. A critical part of the model is a description of the component's physical shape, which is why the normal engineering drawing is such a popular representation. The projected 2-D drawing has several severe drawbacks: however: it is often difficult for even an experienced engineer to visualise the part in the round; we are often interested in three-dimensional clearances necessitating complex trigonometrical calculation; we commonly need information such as volume, weight, position of centre of gravity and moments of interia. If the two-dimensional drawing is correct, all information may be obtained from it, but not directly nor without a considerable amount of work. In CAD, rather than adopting the first or third angle definition, it is possible to represent the part directly in three dimensions, produce views in various projections from any direction, calculate mass properties directly, create finite element meshes and even produce a conventional first or third angle drawing if required. The three-dimensional representation can also be used to produce realistic renderings of the part, in colour, shaded, with specular reflections and surface textures. The degree of realism is only restricted by the amount of time and effort that it is desired to spend on the image since most of the techniques are now known. The three-dimensional representation is called a 3-D model. Two examples follow: one of a surface modeller, one of a solid modeller. These are simple but should be sufficient to give a flavour of the techniques used in 3-D modelling.

A surface modeller—DUCT

56. In DUCT a curved line or 'spine' is defined in a three-dimensional co-ordinate system. The spine is defined by a series of points through which it passes; it may be an open or closed curve and the user has a high degree of control over its shape. At each point on the spine is defined a plane section which can be virtually of any shape, with the restriction that all the sections are defined by the same number of points. Corresponding points on all sections are joined automatically by longitudinal lines and the resultant skeleton surface is covered by curved, four-sided patches. Each patch is mathematically defined so that every point on the surface is known to the system. The resulting curved surface is called a DUCT.

57. We shall model a shape like an aircraft wing. Firstly, two points on an aerofoil section are input in 2-D co-ordinates. The shapes of the lines joining the two points may be adjusted interactively by either keyboard or cursor input. The lines are parametric cubics; their form can be changed by adjusting parameters which determine their end-point directions and their 'bulginess'. When the section has been modified to the user's satisfaction, its details may be stored for future use—Figure 2. A second version of the section, scaled down in this case, is also stored. Next, a spine in three-dimensional co-ordinates is defined (which in this case is a straight line). The number of points defining the line is equal to the number of sections—in this example, two points are sufficient since we have defined two sections. We have now defined two sections and a spine on which to hang them. This defines a 'duct'. This name is rather misleading since it implies that only tube-like bodies can be described; in practice, a wide range of shapes can be formed. The duct (and sections, and spine) can be viewed at all stages in a variety of ways:

- isometrically
- in first and third angle projection
- in perspective
- as a stereoscopic pair

Ducts may also be displayed as coloured, shaded images if an appropriate screen is available.

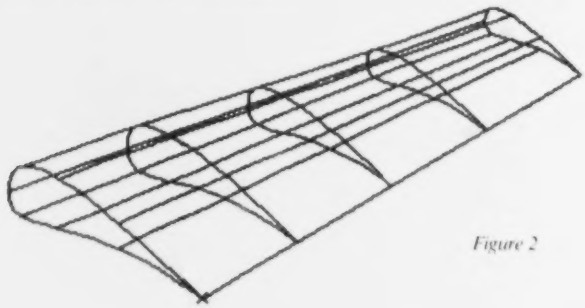


Figure 2

58. Ducts may be modified; in this example, the originally defined starboard wing is mirrored to give a port wing. Both wings are scaled and shifted to form a tailplane—Figure 3. A fuselage might also be added, but this would have to be completely re-defined. Further operations possible are:

- a duct may be automatically blended into another duct in a variety of ways
- split lines for moulding can be determined and draft angles added
- moulding cavities can be produced
- a cutfile can be produced in a neutral format suitable for post-processing for an NC machine. The machining of the duct can be simulated on the screen
- a mesh can be produced which is capable of being post-processed for submission to a Finite Element Analysis program

- if a surface is suitable, then its developed form can be automatically produced
- properties such as volume and surface area can be calculated

Although the example given is very simple, it should serve to give some idea of this very powerful and versatile system.

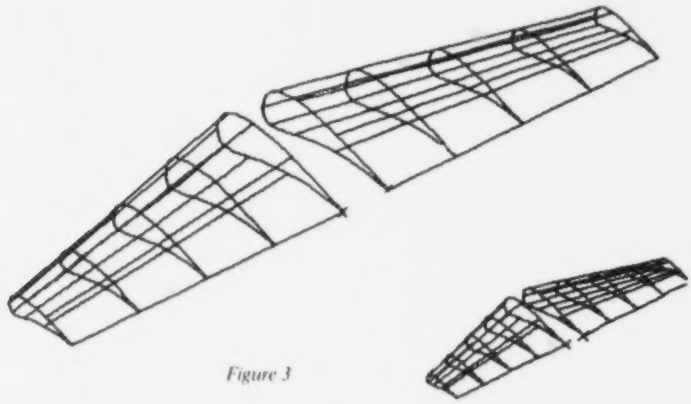


Figure 3

A solid modeller—BOXER

59. BOXER is an example of a constructive solid geometry modeller; it uses five basic building blocks or 'primitives' which are shown in Figure 4. These are placed in a right-handed set of X,Y,Z co-ordinates in standard positions. We shall describe the creation of a model for the casting shown in Figure 5. Note that the model is a considerable simplification; there would be no sharp edges on a physical casting.

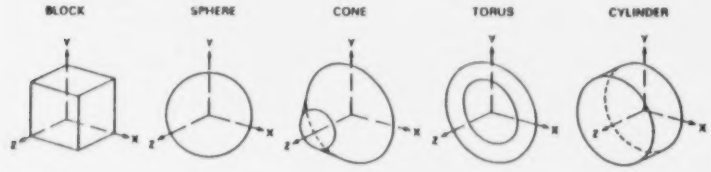


Figure 4

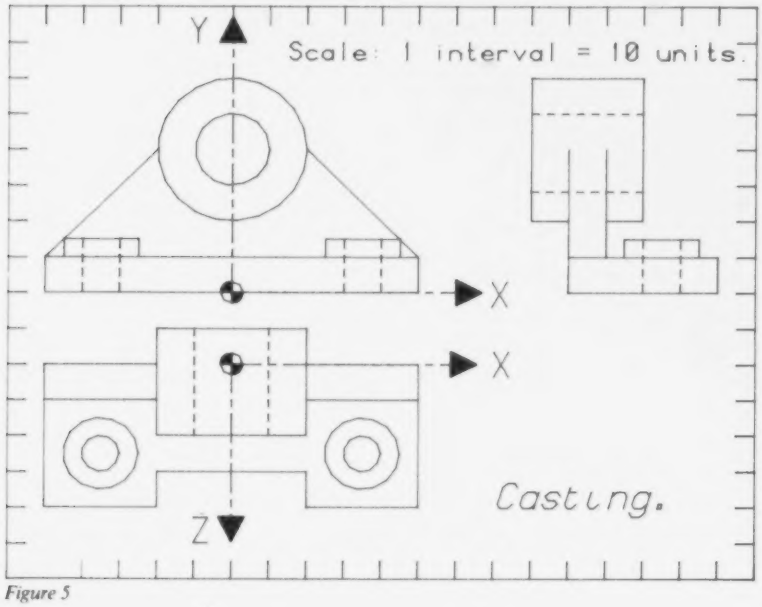


Figure 5

60. On examination, it seems convenient to split up the casting into three parts, the base, the flange and the boss. The casting is placed in a convenient co-ordinate system.

i) *The boss:* This is made up of two cylinders; the smaller, since it is a hole, being subtracted from the larger. We create two 'instances' of the primitive 'cylinder' and move and/or rotate them to appropriate positions in the selected co-ordinate system. Then we subtract the instance representing the hole from the instance representing the large cylinder to produce a solid model of the boss. The operation of solid subtraction is similar to the familiar Boolean set operation.

ii) *The base:* This is composed of six elements, two blocks and four cylinders. These are defined and moved into position. The base is built up by first subtracting the small block from the larger one. Two cylinders representing the bosses are added to the body using the solid addition operator which acts like the Boolean union operator. Finally, the two cylinders representing the holes are subtracted to give the final form shown in Figure 6.

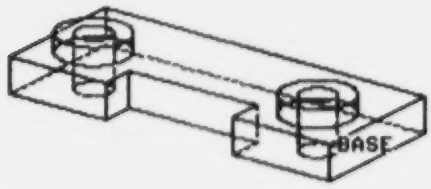


Figure 6

iii) *The flange:* This is made up by defining a block, moving and rotating it to the correct position and subtracting first a block, then a cylinder to give the correct shape. The sides of the block must be calculated; this can be done in BOXER by using numeric assignment exactly like BASIC. The result is shown in Figure 7.

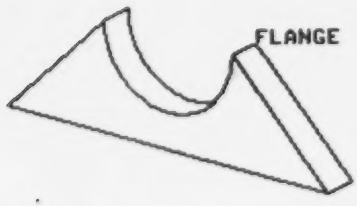


Figure 7

iv) *The whole casting:* This is completed by adding together base, flange and boss. The result is shown in Figure 8.

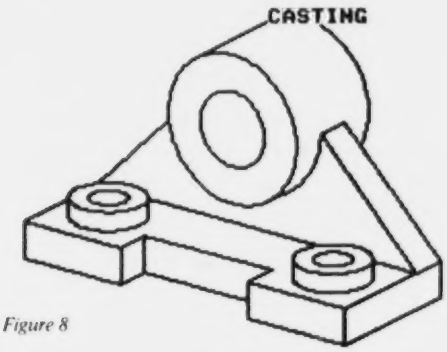


Figure 8

61. The model is now defined. What can we do with it?

- We can view it from any angle in perspective projection—Figure 9

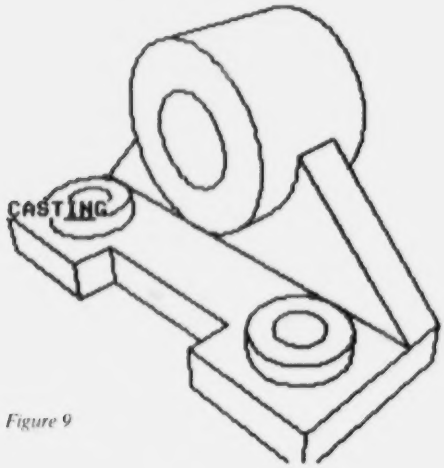


Figure 9

- We can add generator lines to supply some impression of solidity
- We can obtain volumetric and mass properties
- We can display sections through it
- We can produce a conventional engineering drawing of it, pass it through to a draughting system and dimension it
- We can define mating components and define an assembly
- We can create another model representing a housing in which the part is to fit. Then using the solid intersection operator, we can check if there is any interference.
  All the drawings shown have been produced on a low-resolution (512 x 512 pixels) screen and dumped to an electrostatic hardcopy unit.

62. The example gives a selection of the facilities available in BOXER which is typical of CSG modellers. As may be noticed there is no unique way of building up a model and the method used is direct rather than efficient. Most engineers take easily to using such a system since they are normally good at spatial visualisation and can, with a little practice, produce quite complex models quickly.

63. Figure 10 is a model of a robot created in BOXER by an engineering student. It is shown in wireframe form since the

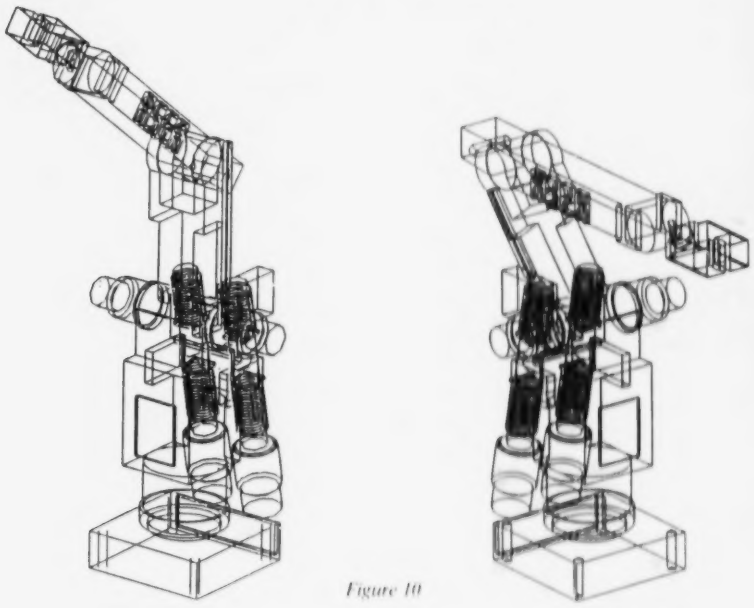


Figure 10

removal of hidden lines in this case adds little to the clarity and takes a long time to process. This model was produced as part of a project to investigate the possibility of using BOXER to simulate the motion of robots. A comprehensive model of an ASEA robot was created and gradually simplified, the processing times being measured at each stage.

5. DESIGN ANALYSIS PROGRAMS

Introduction

64. Ideally, the design database should be capable of being processed by design application programs so that a potential design solution can be analysed in terms of strength, performance, cost, aesthetic appeal and other key factors. In some cases, this is possible; for instance, a surface modeller such as DUCT can be used to supply data to a Finite Element Analysis program. Usually, the three-dimensional modelling system and design application programs are disjoint; they have often been obtained from different sources and, although it may be possible to post-process output from one program to be suitable as input to another, it requires a good deal of programming time. Data is therefore often submitted separately to each system. Not only is this wasteful in terms of time and effort, there is also a problem of maintaining consistency, since altering the data to one program does not automatically alter that to the other. The tying together of disperse programs into a CAD system is becoming more common as firms concentrate more and more on integrating systems through a common database. Although the larger general purpose CAD/CAM systems will already have a capability for linking together a limited range of sub-systems, it is unlikely that even the largest system vendor could supply all of a firm's specialised analysis needs in one cohesive package. There will probably be an increasing need for 'systems-builders'—partly systems programmers, partly engineers—in order to design and organise linked systems. However, there are considerable efforts being made to standardise interfaces, which may ease this problem.

65. In an educational environment, the provision of design analysis programs is difficult because commercial systems are often expensive. There are, however, some micro-based programs which may be used in design classes. Although these are not so comprehensive as the more realistic commercial offerings, they are more suitable for teaching purposes because the training required for using them does not swamp the material being taught. Some examples follow.

SAMMIE

66. SAMMIE is an acronym for System for Aiding Man-Machine Interaction Evaluation. It is basically a 3-D modelling system which contains a standard highly adaptable human model and has facilities specialised to anthropometric modelling. Currently, it runs on minicomputers, such as the PRIME. Although it is not cheap, it has wide applications and so might be bought on a co-operative basis between departments. The solid modeller is used to model workplaces such as cabs of lorries and assembly jigs. It uses a set of primitives similar to those found in other 3-D modellers, and also has a mirror primitive used for the investigation of rear view mirrors.

also has a mirror primitive used for the investigation of rear view mirrors.

67. The most distinctive feature of SAMMIE is the human model. This is a linked set of 19 'bones' in a simplified skeleton. The links are connected logically so that hand movement may result in the forearm and upper arm moving also. The system contains a set of anthropometric data which may be selected by percentiles; the somatotype or 'build', and the model's sex may also be selected. Data can be mixed so that, for instance, 65th percentile arms can be combined with 10th percentile legs. The anthropometric data can be changed if necessary, as can the joint constraints, so that disabled people or operators in heavy work clothing can be modelled. The model can be viewed in perspective or isometric projections. Users can opt to see the workplace as it would be seen by the model placed inside it, and may enter and move through the workplace.

68. SAMMIE is used typically in the design of:

- transportation: cars, buses, trucks, aircraft
- materials handling: forklift trucks, cranes
- manufacturing: aircraft assembly
- interiors: kitchens, offices, workshops

After the appropriate models have been set up, SAMMIE can be used for testing whether:

- operators can reach controls comfortably
- operators will fit into confined spaces
- operators' working postures are comfortable
- operators can see critical areas of the workplace and environment

SAMMIE is very adaptable and is highly cost effective in fields such as commercial vehicle design where it is traditional to make wooden mock-ups of cab interiors. SAMMIE is quicker and can test driver sizes more comprehensively. Figures 11 and 12 illustrate two common applications.

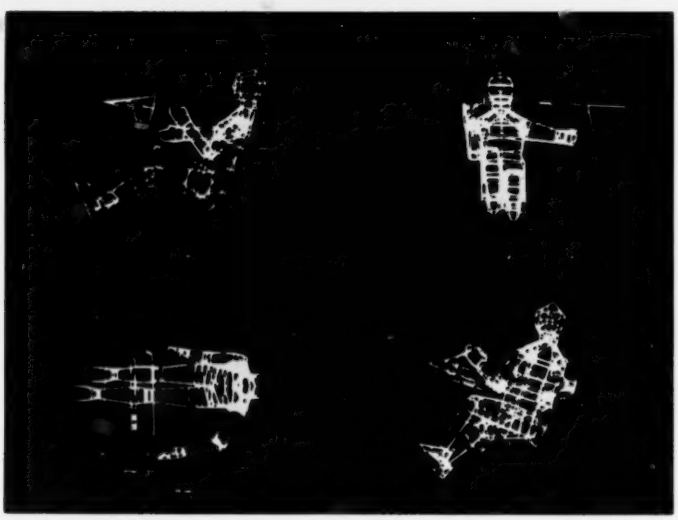


Figure 11

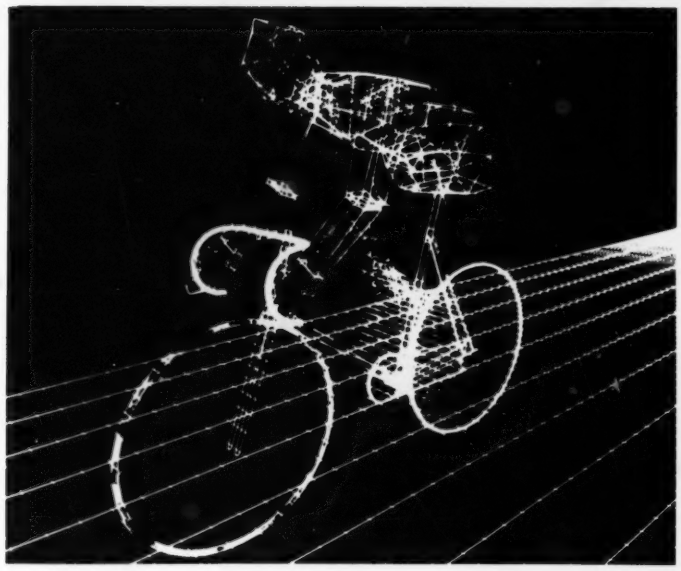


Figure 12

Finite element analysis

69. Realistic Finite Element Analysis programs rely on solving large systems of simultaneous equations to a high degree of precision and so are not yet suitable for microcomputers except in restricted applications. The larger systems use super-computers such as the CRAY for this 'number crunching'. These programs are, of course, unsuitable for use in colleges. In any case, in BTEC units such as the standard CAD V, the time allocated to Finite Element Analysis is insufficient for a detailed study of a full-blown system. A solution is to use a small restricted program specialised to two-dimensional plane stress/strain such as the one used for illustration which runs on the BBC machine. This is obtainable from the CAE Advisory Centre for FE.

70. Because memory is restricted, the program consists of seven separate modules linked by files. The results may be printed out or displayed graphically in colour. The operation of each module will be described.

- SETUP: This generates the finite element mesh. The section is divided into four-sided 'blocks' which may have curved sides; four corner nodes and four mid-side nodes define each block. An example is shown in Figures 13 and 14. When block data has been supplied, the block mesh can be displayed on the screeen for visual check.

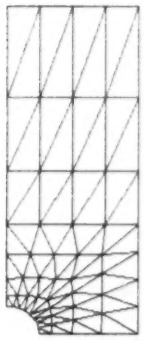


Figure 13 Mesh plot for hole in a tension plate

Figure 14 Principal stress vector plot

- MESHGEN: The data from SETUP is processed to subdivide each block into three-node triangular elements; node numbers, co-ordinates and connectivity of each element are generated automatically.
- RENUM: The numbering system used for the nodes affects the time of processing because of the method used, and experienced users can minimise processing time by skilful selection of node numbers. This module can be used optionally and automatically renumbers the nodes.
- BOUND: The previous three modules have defined the form of the model. This module defines the loads, the restraints and the material properties such as Young's Modulus and Poisson's Ratio.
- CST 1: This module solves the system of simultaneous equations which define the model, the solutions being the displacements at the nodes. From these displacements can be found the element direct and shear stresses; nodal stresses; stresses, loads and deflections at element centroids and principal stresses and their directions.
- CONTOUR: This module produces a simple contour plot of nodal averaged stresses for graphic display on the monitor.
- PRIN: A plot is produced of a pair of orthogonal lines, in the directions of the principal stresses, at the centroid of each element.

Figures 15 and 16 illustrate the calculation of distribution of hoop and radial stresses through the wall of a thick cylinder subject to internal pressure. Processing time for this model is just over six minutes.

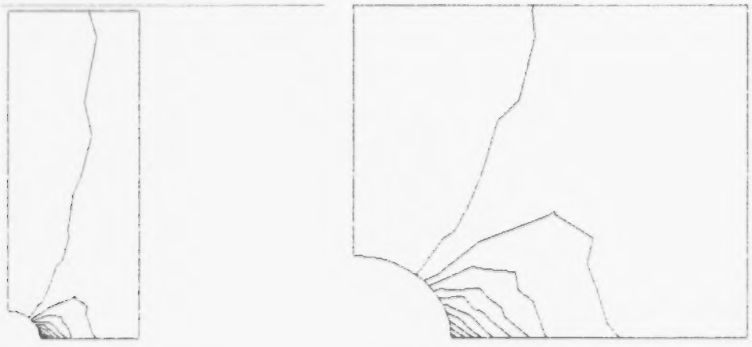


Figure 15 Stress contours of Y-Y stress from FE8 in .2E intervals

Figure 16 Enlargement of hole

Structural analysis

71. There are many programs for the design analysis of structures; an example is STRESS. This is a suite of programs for the analysis of plane and space trusses, frames and grids. The user inputs details of material elastic properties, joint locations and types, structure topology, loading conditions and the results that are required. The output can be displacements, forces or stresses. Although STRESS runs on microcomputers, it is a realistic program and is used by professional construction engineers. In non-specialist courses where

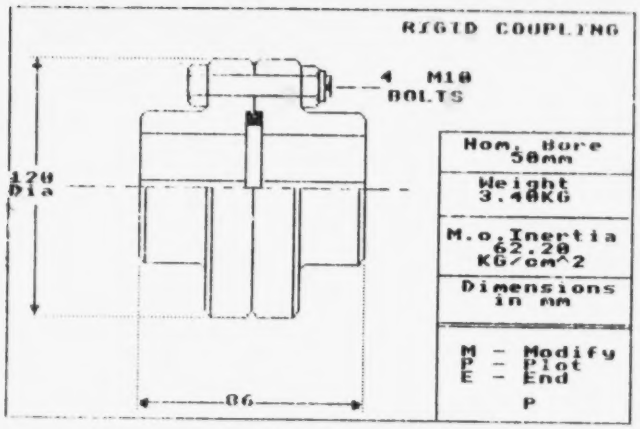
space frame analysis is only a part, the program described in the following section is probably more useful. This runs on BBC machines and is obtainable from the CAE Advisory Centre for FE.

72. The program is specifically designed to be used with BTEC standard unit Structural Analysis V and is used for the analysis of rigid-jointed plane frames such as simply supported, cantilever, encastre and continuous beams and portal frames. It consists of three modules which can be chained together.

- INTRO: gives a sequence of screen displays which describe the facilites and limitations of the program and explain how to prepare the data.
- RIJA: prompts and accepts the input of data, then computes and displays horizontal, vertical and angular displacements on the joints, member end loads, moments, shears and thrusts.
- RIJB: produces graphical or screen dump output of the frame, loading and supports to scale, the deflected form of the frame and the bending moment diagram.

Design of rigid couplings

73. This program is especially useful for colleges which have no specialised CAD equipment but wish to demonstrate the use of computers in engineering design. It was designed in co-operation with David Brown Gear Industries and runs on cheap microcomputers with a low cost plotter. It involves the analysis and design of rigid couplings used to connect two rotating shafts. The program demands the diameters of the driving and driven shafts, the rotational speed in rpm, the power and torque. It then searches a database to select an appropriate standard coupling from a list of David Brown Gear Industries couplings type 629. This coupling may be drawn in correct proportion on the screen together with the weight and moment of intertia. If a power or torque is specified which is above the allowable values for mild steel shafts then the design may be modified and the program re-run. If a plotter is available, then an engineering assembly drawing of the coupling can be produced with a parts list on the printer. An example is shown in Figure 17. The program demonstrates the analysis of a common machine element with design iterations together with the production of a drawing and parts list. The theory is simple enough for the design solution to be checked manually and includes some analysis of hoop stress, keyways, bolt sizes and tightening torques. Again, the program is obtainable from the CAE Advisory Centre for FE.



Drawing No. RC001
Customer FLANNIGAN ENTERPRISE
Date of Issue 22-09-87

Item No.	Description	Quan	Matl
1	Hex. Bolts M10X1.5--45 Long	4	Grade 8.8
2	Nyloc Nuts M10X1 5	4	
3	Rigid Flange Half Coupling	2	070M20 (EN3A)
4	Location Ring	1	220M07 (EN1A)

Figure 17

- SWITCHSMITH: a timing simulator for MOS designs which operates at the transistor level. The input comes from MODEL or other compatible HDL.
- DRAFTSMITH: a logic capture system complementary to MODEL. It is a versatile schematic editor which may be used in many CAE workstations.
- CHIPSMITH: an integrated design system for CMOS integrated circuits using silicon compilation techniques for implementing gate arrays and standard cell designs.

These software tools provide compatible input/output. For instance, the input to CHIPSMITH may come directly from MODEL or DRAFTSMITH, while MODEL will also interface with the SWITCHSMITH simulator.

81. Many other similar software tools are available which will run on virtually all modern workstations from the major manufacturers. Specialised workstation suppliers such as Daisy with its Logician and its IBM PC-AT based Personal Logician provide suites of software tools enabling users to create, compile, model, simulate and document their designs. The PC-DOS operating system provides complete compatibility with a wide range of commercially available software packages.

82. Typical of the support facilities offered would be a component library including all the characteristics of a range of components, for instance:

- TTL 7400 and 5400 series
- ECL 10K, 10KH and 100K series.
- CMOS 400 series
- HCMOS 74 and 54 series
- Memories
- PLAs and PALs
- Microprocessors and their peripherals

In addition to standard libraries, user-defined components can be created and used in designs.

Application to FE

83. The advent of PC-based design facilities through operating systems such as PC-DOS enables colleges to introduce this type of software into their courses within a limited budget. It is, however, imperative that industrially oriented education and training should be based on up-to-date industrial technology. This technology requires the use of a CAE workstation which will enable the designer to:

- lay out the design using component libraries (normally referred to as 'schematic capture')—including ASICs
- simulate the required performance and debug the circuit through the user specification of test vectors
- perform automatic PCB routing based on component specification
- generate documentation

The provision of electrical/ electronic CAE in education

84. In March 1986, the University Grants Committee (UGC) announced that £25 million of VLSI design software would be provided to British universities to facilitate the teaching of microelectronic circuit design in undergraduate courses. This scheme has been expanded to include the polytechnic sector. The range of software products provided includes those supplied by:

- Silvar-Lisco: full custom design facility
- Racal-Redac: full custom ISIS design system
- Genrad: HILO 3 simulator
- Silicon Microsystems: all cell-based libraries
- Qudos: educational package based on the BBC machine.

It can be expected that products not on the original list will be available for hardware such as the IBM AT Personal Computer, an example being the Daisy Personal Logician.

Implications for FHE

85. The effect of this initiative is clearly to establish integrated circuit design as a component of all electronic engineering degree courses. It follows that colleges will need to introduce appropriate course material, particularly at the Higher Diploma level. The facility now exists for student-designed chips to be actually manufactured at reasonable cost. At the time of writing, the first examples of a multi-project chip have been produced, based on designs submitted to Micro Circuit Engineering by the University of London consortium. The entire undergraduate electronic engineering population of students from both universities and polytechnics is expected to be able to use this service in the late 1980s. It is anticipated that silicon circuits will be manufactured twice per year. As an example, if a four-inch wafer is produced containing about 600 chips, it would allow about 30 different projects to design and manufacture 20 chips each. It is well known that chip yields are variable, but assuming, say, 40% yield, then on average, each project would receive eight working chips for each design.

Low-cost chip design and fabrication

86. Students may also gain valuable experience through semi-custom gate array technology and a remarkable low-cost semi-custom design and chip fabrication facility is offered through the Qudos design package, which is available on the BBC microcomputer. This educational design tool permits colleges to demonstrate the principles of gate array technology and allows students to implement designs without the complexity and cost of the full custom design facilities. Also, the use in Qudos of electron beam lithography allows colleges to implement their own multi-project chip facility based on gate array technology.

7. CAD IN BUILT ENVIRONMENT EDUCATION

The range of disciplines

87. The discipline most readily associated with CAD in the built environment field is architecture. The range of users (or potential users) is much wider, including civil engineering, structural engineering, building services engineering and the surveying disciplines, particularly building surveying.

'Industry standard' CAD systems

88. In courses which are clearly vocationally oriented, a major aim in using CAD is to provide students with the opportunity of experiencing 'industry standard' technology. The major difficulty in fulfilling this aim is cost. The systems sold by the market leaders in architecturally based CAD systems can cost £70,000—£125,000 for a single workstation. An additional revenue charge for maintenance can amount to 7%—15% of capital expenditure per annum and extra workstations can cost approximately £12,000 each. Most departments and schools of study find the justification of this level of investment for one workstation difficult to substantiate. This applies to universities and polytechnics offering honours degrees and postgraduate displomas, besides those offering professional or technician courses in architecture and related disciplines.

89. The type of system outlined above would normally require 32-bit minicomputer type hardware. Typical hardware configurations of this type are:

- DEC MicroVax
- Data General MV2000
- Apollo Domain
- Prime 350/550

A specific example is the ARC system which requires a MicroVax with 2Mb of main memory and a 71Mb disk or Prime 2350 with 2Mb main memory and 120Mb disk as alternative hardware configurations. This, or more powerful mainframe hardware, may already be in use within the institution; by using existing hardware such as the CAD system's CPU, costs can be reduced. There are, however, several factors which need careful investigation before any commitments are made. The primary question is whether the existing facility will be able to cope with the extensive CPU time required by sophisticated systems such as 3-D modellers. Most institutions' mainframe facilities are mainly concerned with the provision of a multi-user terminal service, the demand for which is high. Very often, the bulk of the processor's time is taken up with running small BASIC or PASCAL programs and the drastic change in running more 'number-crunching' jobs may result in a rapid deterioration in response. As most systems have little spare capacity, the best

that one may realistically hope for would be several scheduled periods each week during which the CAD facility is running and the multi-user system is either not running or is restricted. As the multi-user fraternity have, by definition, force in numbers, negotiations over this issue need to be undertaken delicately and diplomatically. In any case, it is necessary to proceed with care when extra facilities are being demanded from multi-user systems, since it is well known that they do not 'gracefully degrade'. Extrapolation from existing response time is not a reliable predictor of future response when the system is extended.

90. A second factor, perhaps obvious, but of such importance that it merits mention, is the detail of compatibility between your own hardware and that of the CAD system. A particular issue is the operating system, its version number and current (or expected) revision at the time of delivery of the CAD software. This detailed level of specification for ordering is usually best left to the computer manager in liaison with the potential suppliers.

91. ARC, GABLE and RUCAPS each provide a full computer-aided 2-D draughting and 3-D modelling/visualisation facility. Typically, an ARC fully configured single workstation system with high resolution colour graphics, hardware, software and furniture is available to education providers at a price of £50,000. The benefits of gaining access to such systems as these have been extended in recent years by the ability of many to accept data from compatible software (particularly ground modelling packages using land surveying data) and to generate building evaluation information from the models created. This advance is analogous with the move towards integration in the manufacturing industries and brings the same benefits.

92. A particular example of this type of facility is the GABLE 4-D series GMS (Ground Modelling System) which accepts land survey data to provide 3-D visualisation in various forms, contour plans, cut and fill estimates. Similarly, the ARC system enables input via SITES to create the same form of model. In this instance, data can be collected on site using, for example, a HUSKY portable microcomputer. The data file is then read into SITES for the site model creation. The evaluation facility is typified by GABLE's ability to provide:

- overall heat loss and seasonal heat loss
- part F/FF Building Regulation checks
- daylighting
- sunpatches
- condensational checks through any surface
- sound insulation calculations for any surface
- U-value calculations for any surface
- counts, areas and lengths of unit elements and junctions

Lower cost systems

93. If the foregoing system types—and costs—are beyond expected resource availability, lower cost systems now provide high performance capabilities with less significant drawbacks than previously experienced. One example of an excellent low cost/high performance system (also referred to in Section Three) is AUTOCAD. The current version is able to run on over 30 different microcomputers with drivers for over 30 plotters, more than 40 graphics tablets and a wide range of video display options available. The microcomputers must, however, run MS-DOS/PC-DOS 2.0 or above and should also have a minimum of 512K RAM (preferably 640K) and two serial ports. An 8087 arithmetic coprocessor and a hard disk will enhance speed of operation dramatically.

94. The ADE3 facility of AUTOCAD provides 3-D visualisation which includes 3-D wire frame and drawing views from any specified point in space; there is a HIDE command which provides simple display or plot of solid objects. In addition to the LISP facility (mentioned in Section Three), the ATTRIBUTE command enables data generated from drawings and specified as 'attributes' (lengths, areas, volumes, references, names, etc.) to be stored in an ASCII file which can be read by other packages including databases, spreadsheets, other programs (e.g. BASIC routines) or post-processors. This provides users with the capability of tailoring their own evaluation routines and expands the application of CAD to those interested not specifically in building design itself but in the implications of design decisions, for example, builders, quantity surveyors, estate managers and planners.

95. An excellent feature of AUTOCAD is the large number of specialised applications programs that can be bought to go with it. Some of these, chosen at random from a list supplied by AUTODESK, are:

- Terrain model builder
- Contour map plotting
- Cross-section generating
- Terrain model digitisation
- Bill of materials builder
- Take-off and estimating
- Steel detailer
- STRUPAK: Analysis of steel and concrete members

96. Another approach to low cost CAD is to provide 3-D visualisation without the facility (or need) to draft the original plans, elevations, etc., within the system. SKETCH-IN-DEPTH is an example of such a package. Data is input, normally using a digitiser, from a manually drafted plan. Each elevation (or 'aspect') digitised requires a height input and the user creates various 'box' forms which are built together into a 3-D model of the building. This can then be

viewed from any defined point in space. An object library file of commonly used shapes can be created, enabling rapid input of multiple items (internal fittings, entire standard buildings, etc.). Thus entire sites can be viewed in 3-D following input of standard units plus lines to denote site boundaries, kerb lines and the like. The package is available on a range of MS-DOS microcomputers; output can be taken from plotters or good quality dot-matrix printers. The same firm also offers MEASURE-UP (area and length calculation from digitised input) and SITE SURVEY (plots, plans and contour plans from site survey data). Other examples of the increasing number of micro-based systems that are coming onto the market are:

- CAPITAL, a full 3-D visualisation system supporting wire-frame modelling, paint routines, digitised input, sketch-on-screen and many other facilities
- GINGA, a 3-D modelling and 2-D draughting system permitting perspective and axonometric views and which is specialised to architectural use

An excellent source of information and advice is the CICA/RIBA Software Selector obtainable from the Construction Industry Computer Association at a price of £12.50 (free to members).

Conclusions

97. It may be noted from the above that two distinct markets exist in totally different price ranges. In many cases the decision on market level will not exist—the upper sector will be out of the question. If this is indeed the case, a single basic workstation may be the solution if currently owned microcomputer hardware can be used as the heart of the system. The major variable at this level is the plotting facility, the cost of which can vary from that of a dot-matrix printer, through an A3/4 single-pen plotter, up to a large AO multi-pen plotter.

98. In the upper price range, the benefits of state-of-the-art technology are necessarily costly and systems are ephemeral. Major architectural practices are known to have spent sums in excess of £500,000 recently to replace previous investments only five years ago of £100,000. Much greater effort will therefore be needed to justify initial expenditure and continued efforts must be maintained to ensure that future replacement costs are justified. Where the system allows, education and training can be offered to interested professionals in the field to generate income. This continuing professional development activity can provide:

- a key to justification for expenditure on the system
- income generation
- stronger links with associated professions
- a sound basis for staff development

8. CAD FOR ART AND DESIGN

Introduction

99. The introduction and use of CAD within art and design education is of increasing economic importance since design is a major factor in successful industrial competition. The national validating bodies for FE and HE are aware that art and design should keep pace with the needs of industry. However, the speed of technological development presents problems for teachers who do not have a background in technology.

100. Although there have been a number of regional and national initiatives (for instance, the PICKUP CAD training scheme for Yorkshire and Humberside Association for FE, 1986), most work on computing in art and design has been carried out in isolation often leading to duplication of effort and inefficient resource utilisation.

The art and design problem

101. A number of factors have complicated the introduction of this new technology into art and design education:

- the technology itself is rapidly changing
- until recently, there has been a lack of suitable, inexpensive software
- the design process is ill-defined and there is much debate on the nature of creativity
- each course and institution has a different approach towards design teaching
- teaching staff in art and design are unlikely to have sufficient background in technology
- there is a scarcity of resources presented by the current constraints in education and training within further and higher education

102. As a result, uncertainty continues to surround the introduction of, and approach to, CAD. Despite some staff development, conferences, financial incentives and directives from BTEC, CNAA and the DES, response has been patchy and poor. This reluctance to use computers probably stems from the attempts in the 1960s which were often frustrated by the (then) unwieldiness of large, very expensive mainframes. Users without technological training operated these ineffeciently; training time was disproportionate to results achieved and aspects of this are still in evidence today.

103. There has also been a tendency to treat computer studies as a separate subject with a mathematical bias rather than as a fundamental part of the curriculum and there is

much debate as to whether a subject specialist or computer scientist should do the teaching.

104. Since there has been little substantial research into the role of computers in art and design education, there is no formal basis for the design of learning experience, a situation which has been described as 'theoretical impoverishment' (D.J. Smith *Information Technology and Education—Signposts and Research Directions* ESRC).

105. This lack of direction is not only wasteful of scarce resources, it also has serious implications for industry, since CAD gives firms a chance to be successful in surviving fierce competition. Consequently, there appears to be a need for a co-ordinated programme of research as well as staff development and training.

Future requirements for computing in FHE art and design

106. The recent explosion of information technology in general and CAD in particular could revolutionise the design process for both education and industry. An FEU policy statement (*A Framework for Action in IT: Information Technology in FE,* 1984) presents three dimensions of IT for colleges as:

- computing within the curriculum
- computer-aided learning
- computer-aided management

107. In art and design, the following criteria should be considered:

- Specialist applications for art and design (computing within the curriculum): case studies of good practice and the role of computing within the design process and design activities.

  Aim: to allow an understanding and experience of the range and scope of computing for art and design.
- Computing as an aid to professional practice for design management (computer-aided learning): the role of computing within professional practice including business management, office practice, information processing, administration and communications for industry and commerce.

  Aim: to provide a base for cost effectiveness, professional management and industrial survival.
- Course, department and college management and organisation (computer-aided management): the role of computing for administration, communications, inform ation processing, records, evaluation, forecasting, budgeting, ource and course planning, liaison with industry, education and research.

  Aim: to facilitate and optimise course, department, college and resource management.

108. In assessing these criteria, sufficient regard should be given to the interdisciplinary nature of computing arising from the integrative effect of CAD and CAM (CAD/CAM).

Specialist applications for computing in FHE art and design

Case studies of good practice

109. There is no set precendent for use of computers in art and design and no one accepted centre of excellence. However, there are a number of institutions which have developed an expertise in certain specialist applications and therefore present a sound resource for case studies of good practice.

110. For example, at Teesside Polytechnic Department of Interior Design, computing has been built into undergraduate basic design studies as well as applied 3-D modelling and visualisation. Designers worked closely with computer scientists to develop their own software for use on a microcomputer (e.g. CAPITOL) running on the Apple II, Apricot and IBM PC) and minicomputers (C'GAL, VAMP running on the Apollo). Here, liaison was fostered between interior, industrial and engineering design departments.

111. In North Staffordshire Polytechnic's Multidisciplinary course, a number of computing systems have been set up using commercial software on a variety of machines ranging from BBC machines to powerful dedicated machines. Students work on a common design brief and develop ideas through computing into production for industry in either 2-D design for print (graphics or surface pattern) or 3-D design for manufacture (ceramics). Close links have been forged with Staffordshire potteries to develop CAD processes.

Activities within the design process

112. There is a need for courses to examine the role of computing within the design process and design activities both for education and industry. Although it is recognised that there are many different interpretations of what is meant by art and design, the use of computing may be considered as an aid to the following activities:

- understanding basic design concepts/aesthetics, e.g., line, form, shape, colour, space
- exploration: printing or dumping screen generated images
- building-up or working on a specific design brief or project
- testing the feasibility of a specific design proposal
- production of a graphic visualisation suitable for client presentation
- draughting and plotting (the production of detailed construction plans)
- printing, typesetting and electronic page make-up
- testing and modification, once the design is in production
- design management: word processing, business transactions (accounts, contracts, specifications, etc.), records (student, project, assessment), database technology

- consultancy: intelligent systems (expert systems) with which design problems may be discussed

In some cases, these activities may be viewed independently, in others as part of an interactive CAD/CAM process, which may completely alter the approach towards design for industry and education. For example, the use of 3-D modelling systems could mean that detailed construction plans are unnecessary for some applications and design for print is already undergoing a much-publicised revolution.

113. Consideration should be given to such issues as:

- the economic importance of CAD
- extended scope for design, research and industry
- the cost in terms of time, human and physical resources
- problems of misuse, stress and re-adjustment
- the need for critical appraisal and design judgement
- recommendations for management policy
- staff development
- computer literacy and awareness
- computer-based learning
- communications
- storage, access and retrieval of information
- level and standard of involvement
- regional and national initiatives
- links with industry and schools

It is important to develop a coherent policy so that the maximum benefit can be gained from the integrative nature of computing coupled with a major review of design education. A 'tack-on' computer studies approach just will not do!

Computing as an aid to professional practice

114. Computing as an aid to professional practice is an aspect which has not yet received attention in many colleges but is likely to prove one of the most important developments for design management in both education and industry. A notable exception is Cumbria College of Art where the policy within the department of design has been to concentrate on design management. As a result, industrial liaison has been strengthened and considerable resources generated, allowing expansion of both design facilities (e.g. interactive video) and course potential. For example, the development of a video workshop has led to commissions from local agencies such as the Cumbria Tourist Board.

115. Professional practice may be considered on three levels—design management, design teaching and office practice.

Design management

Objective: to present a range of uses for computer technology in design management for industry and commerce:

- approaches to problems
- approaches to solutions and product
- project control
- decision making
- simulation modelling and calculation
- design information retrieval
- communications between designer, client and user
- research and development

Design teaching

Objectives: to examine some current and possible future applications of computing technology for staff and curriculum development in Further Education:

- the effect of new technology on design teaching, education and industry
- management style and attitude
- interdisciplinary communications and co-ordination
- team building and dynamics

Professional practice

Objectives: to explore means of data handling and processing that form the basis for design decision making and planning:

- collection, storage and retrieval of information
- wordprocessing and editing
- information analysis (validating, sorting and calculating)
- communications
- controlling design processes and methods

Course, department and college organisation and management

Computing policy

116. A policy for resource management at all three levels (specialist applications, professional practice, college and course management) is essential to ensure equipment compatibility, operating standards, access agreements and technical support if real gains are to be made from such a major investment.

Organisation and administration

117. Commercial computing systems for business and even college management already exist. For example, FEMIS, the Further Education Management Information System developed at the Coombe Lodge FE Staff College. This includes aspects of college resource management such as academic staffing and timetable analysis, room utilisation, costing and financial analysis and planning and budgeting.

Priorities for the development of computing in art and design education

118. There is evidence to show that there is a need for a programme of sustained support in three areas:

- staff development and training (practical application)
- an understanding of CAD and its place in art and design, and industry (research and development)
- access to technical advice and support

Staff development and training

119. Provision for staff development and training (computer literacy, specialist applications, design managment) might be made through a co-ordinated programme of regional seminars, workshops and demonstrations. Such a programme could be supported by the collation and development of training materials and examples of good practice.

Research and development

120. A fundamental understanding of CAD and its place in art and design and in industry is essential if real benefits are to be gained from the application of this new technology. An understanding is also vital for curriculum development and resource planning. For example, high speed technology can put increasing pressure on the designer to meet much shorter deadlines and there may no longer be a gestation stage in which designers have traditionally been able to review and amend their work. It may well be that future designers will work in a substantially different way from today's designers and, in order to design effective user interfaces in the systems of the future, considerable research must be carried out into the nature of the design process. It will be necessary for our courses to include some treatment of these new working procedures.

Access to technical advice and support

121. There will be a regular need for access to updated technical information and advice in order to keep pace with developments in computing and to maintain existing resources.

Conclusions

122. It is recognised that a good deal of research needs to be done in this area and there are some indications as to what form this could take. In order to classify and assess priorities and to develop an approach towards computer aided design and its place in the curriculum, it may be helpful to separate issues into three categories, each of equal imortance. This categorisation may help to define the role of computing in art and design, and establish its place in the design curriculum:

- issues which are to do with the technology itself, including its advances and limitations
- issues which are related to a transitional phase during which artists and designers become familiar with the technology
- long-term considerations which are fundamental to resource and curriculum planning for art and design education.

123. It is suggested that a network of expertise could be identified to cover the spectrum of interests in art and design. By enlisting the services of leading practitioners and researchers, advice could be 'bought in' to meet the requirements of individual specialist courses on a

consultancy basis. Payments would be made through an annual subscription. This advisory service would be co-ordinated and administered nationally. In order to present a considered direction for art and design development, there appears to be a need for a co-ordinated programme of research to match the large investment of finance, time and effort.

124. All individual colleges should devise (and regularly review) an internal policy for computer resource management, staff training and curriculum development.

125. Regional Advisory Councils should play a sustained supportive role in developing computing for art and design, liaising with schemes such as PICKUP and Local Collaborative Projects.

126. National bodies such as DES, DTI, and professional organisations such as SIAD, CBI, Design Research Society and ACADE should make a concerted effort to support CNAA and BTEC in developing a national policy for the future of computing in art and design education and training.

9. SYSTEM SELECTION

Introduction

127. Although the cost of CAD systems has decreased over the last couple of years, the investment in a system still involves a considerable proportion of the total funding available to most departments and it is important that a system should be selected in a reasoned and effective way. It is, for instance, undesirable for discrete sytems for CAD and CAM to be bought, even if the money is available to do so. Many of the systems currently on sale have provision for linking CAD and CAM and it is advantageous, from the outset, to take a unified view and consider a CAD/CAM system. Since two fields of specialisation are then involved, the selection must take into account both interests. Sometimes it might be considered cost-effective to use the same hardware for several departments. This makes the process of selection even more difficult. Occasionally the funding for a CAD/CAM system arrives unexpectedly in colleges so that selection and purchase must be hurried. It is advantageous if a contingency plan for CAD/CAM provision exists in order to ensure that the purchase matches the needs; devising such a plan is a useful staff exercise in its own right even if the desired system is not immediately forthcoming. A contingency plan is useful for other reasons, also. For instance, bids for equipment are more plausible if backed by a previously declared strategy. The procedure for system selection and implementation, which will be described in outline, is a fairly standard exercise in industry.

Stage I. Organising a CAD/CAM task group

128. There are various technical and educational aspects to be considered when selecting a system and it is not desirable that the process should be the responsibility of just one person, since it is very unlikely that he or she would have sufficient breadth of expertise to make a satisfactory choice. It is usual, in industry, to set up a Task Group with members drawn from different fields. The Task Group is a centre of expertise; it is responsible for gathering information about systems, for analysing departmental needs, for selecting a system to satisfy them and for organising the purchase and installation of the selected system. The ideal size for the group is from four to six members of varying expertise, a good mix being design, production, information technology with possibly a co-opted member with business studies knowledge. A team leader should be appointed (or elected) who will convene and run meetings and through whom all external communication should be channelled. Even after a system has been bought and installed, it may still be useful to maintain the group for the development of staff training programmes and to devise procedures for the day-to-day running of the system. It is possible that the selection of a

system might be the responsibility of a department, a college or even the LEA; in each case, the procedure would be broadly the same.

129. Initially, the group should set about gathering as much information as possible about CAD/CAM systems in general. It will be rapidly discovered that there is no shortage of information about systems and it is probably more economic of effort to concentrate on systems that might, realistically, be expected to be purchased than to consider the whole range. It is useful to visit colleges of similar profile which are already involved in CAD/CAM, to see how the various systems suit an academic environment and to gauge the staff's reaction to them. Although users are often rather uncritical of the system they use, it is instructive to share ideas about teaching methods, organisation of practical work and staff training. It is also useful to visit local firms, for although the systems they use might be beyond a college's means, the liaison may lead to opportunities for staff training placement and eventual short course provision.

130. If possible, a sense of urgency should be engendered in the Task Group even if the chance of obtaining major funding is remote. New systems arrive on the market very frequently and it is desirable to monitor continually the systems currently on offer in order to keep up to date.

131. System vendors are usually happy to give information about their products and will also help with details of other academic users. It is best to be truthful with them, explaining that the exercise is only exploratory so that a good relationship is maintained.

Stage II. Analysing departmental needs

132. A major problem is the compromise between conforming with industrial standards and getting sufficient workstations to ensure an adequate student throughput. Ideally, a college should have two systems: a high quality commercial system for specialised CAD/CAM courses and a low cost system for general academic use. This is not just a matter of cost; most expensive systems need a comparatively high degree of training before any practical use can be made of them. This overhead is not so high for more modest systems and so the latter are more suitable for courses not specialising in CAD/CAM.

133. There are many relevant factors to be considered. Some are:

- variety of disciplines using the system, e.g. art and design, mechanical, electrical engineering
- existing facilities, e.g. central computer system, micro-computers available
- course profile, e.g. short courses for industry, part-time day release

- degree of commitment to CAD/CAM, e.g. departmental ambitions of running specialised courses, desire to introduce CAD into existing design courses
- student throughput, e.g. raw head count, percentage of time to be spent on CAD/CAM
- student attendance profile, e.g. part-time day release courses clustering on one or two days per week
- college opening hours

134. This information must be analysed in order to arrive at a system specification. This should be a bald, non-technical statement of the resources required to meet departmental or college needs; the list can be prioritised. A sample system specification might be an expanded version of the following:

Software:

- draughting system suitable for mechanical and construction engineering
- tape preparation system with post processors for NC lathe and mill
- Finite Element Analysis system
- solid modelling system

Hardware:

- workstations; using existing microcomputers, ideally twelve bitpads to drive the workstations
- A3 flat bed plotters, ideally two
- drum plotter
- hard copy printers, ideally one per workstation

135. A basis for the quantity of hardware might be: one workstation between four students for specialised CAD/CAM courses with practical work occupying about 50% of the total time and students working in pairs; one workstation between two students for short courses for industry with practical work occupying about 75% of the total time. The location and layout of the system should also be considered in general terms at this time.

Stage III. Choosing possible solutions

136. If no cash is available, the exercise will end with the system specification and the procedure should be repeated at reasonably frequent intervals. If money is available, then the system specification may have to be tailored to suit the amount in hand. A better prodedure, perhaps, is to retain the original system specification as a target, to inform vendors of the money available and to let them respond with suggested solutions which may fall short of the target.

137. From the information gathered in Stage I, a list of potential suppliers of suitable systems may be prepared. There are a few general rules that are useful not only for CAD/CAM systems but also for microcomputer equipment in general. If you are well conversant with CAD/CAM equipment, you will probably get the best deal from a hard-sell 'box mover'; if, on the other hand, you have little experience, it is essential that you should have a good deal of initial support in configuring the system and answering general queries. In either case, it is best to buy from a vendor who is local. It is also useful to buy a whole system from one supplier so avoiding the 'shedding the blame' effect when the system goes down. Many suppliers provide free training courses; although these may not always live up to expectations, you will pick up some training notes to augment the manual. Occasionally, training is not available when academic discounts have been applied. It is worth investigating whether site licences are available also.

138. From the replies to the inquiries, it should be possible to select a short list of up to six vendors. It is appropriate to consider the provision of colleges in the area at this time. If it is desired to run short training courses for industry, then it is clearly advisable to get a different system from that used by a college a mile away otherwise you will both be fishing in the same pool. It may, on the other hand, be helpful to buy the same system as a college twenty miles away—this type of 'twinning' is potentially very useful.

Stage IV. Invitation to tender

139. At this point, the short-listed suppliers should be invited to tender. They will provide a technical proposal and quotation. The technical proposal will specify the hardware and software proposed; the quotation might include price, terms of contract, details of warranty, available maintenance for both hardware and software, inclusion of manuals, menus, training courses and installation. Usually, the terms of the quotation are valid for a fixed period, often 30 days.

Stage V. Selecting a system

140. The short-listed suppliers who have submitted a quotation may be invited to demonstrate their wares on a benchmark of your own choice. The complexity of this will depend on the money that is being laid out but even the simplest test exercise is better than the vendor's well-practised demonstration party-piece. It may be that, at this stage, a suitable system has been chosen but no decision has been made about the supplier. The major criteria for small systems are the technical expertise of the supplier's staff and the commercial viability of the supplier's firm. These factors may often be judged by observation at the vendor's premises. Normally, in industry, a system is only accepted when it is running satisfactorily. Colleges should try to observe industrial practice in this respect. After the order has been placed, it is courteous to inform unsuccessful dealers that their quotation has not been accepted.

Stage VI. Managing the system

141. The system manager chosen should ideally have been part of the Task Group thus ensuring commitment to the system. A crucial part of the manager's job is the design and implementation of running procedures so it is wise to select someone with organisational interest and ability even at the expense of detailed technical expertise. Whether the system manager will work full-time on the system depends on its complexity and size but it is important to note that the organisation of even a modest installation takes up a surprising amount of time, particularly in the early days.

142. The system manager will have responsibility for the CAD/CAM room layout; normally the initial layout is found to be unsatisfactory and the ideal is only arrived at by a good deal of experimentation. A few points to bear in mind are:

- the position of the workstations is important. There should be minimal reflection from the screen; the room should ideally be decorated in a darkish matt paint. There should be easy access around the back of the users so that staff can easily monitor students' progress. In order to minimise tampering with switches, it is best to have the back of the screen inaccessible to users;
- power supplies and cable routing should also be considered although it is best to leave trunking for a while until the layout has been settled;
- the CAD/CAM room should not be used as a lecture room unless it is unavoidable, although it is useful to have a whiteboard available;
- secure storage should be supplied for software, manuals, menus, plotter pens and stationery;
- wall displays should be restricted to system information, for instance, on how to get into the system;
- a booking system should be provided and it is best to avoid all the screens being booked *en bloc* if possible. If the CAD/CAM room is not a lecture room, students should be encouraged to use any available screens even if a supervised class is in the room;
- tables should be provided for students' bags and effects;
- simplified documentation—if possible, one A4 sheet—should be provided for each system;
- some attempt should be made, on microbased systems, to avoid students copying the system. Students' drawings should not be kept on the hard disk but on their own floppy disk or you will soon run out of storage;
- it is best to restrict any up-grades to the system to the end of the academic year, since even minor changes in operating procedures can be very frustrating to students.

Stage VII. Staff training

143. If staff are to use a system with a class, there is no escaping the fact that they must spend a lot of time actually using the system and that just reading the manual is not enough. In an industrial environment, systems are normally used in a controlled and disciplined way. By contrast, students tend to use systems much more creatively and find

their way into remote corners of the system very frequently. It is essential that staff should be conversant with all the facilities of a system and be fluent in its use; this involves a good deal of personal effort. However, they can be helped in the initial stages in several ways.

144. It is good for staff to share experiences in using the system and a log book can be used for them to write down difficulties and discoveries. Periodic short training sessions also present a forum for exchange of information. A user group, if one exists, is an invaluable source of handy tips and, even if you cannot send a representative to the meetings, the newsletter is usually instructive.

145. Training is often better if staff work as 'running mates', in pairs. This has many advantages: it avoids staff keeping techniques to themselves; they can share the responsibilities of operating the system and recording findings; and, generally, because of synergetic effects, progress is more rapid. Where a training course is provided with the system and equipment is limited, it is efficient to organise training on a tree-structured basis where the member of staff who has attended the course trains two members of staff who also train two and so on. This avoids the 'sole repository of information' effect which is neither very efficient nor beneficial.

146. The following is an account of how Birmingham Polytechnic Department of Mechanical and Production Engineering has tackled the problem of staff training; this is part of a rolling staff development programme.

- A list of staff who would profit from training in CAD/CAM techniques was prepared.
- A representative of the Department of Trade and Industry was invited to discuss our needs and advise us. With his help, we prepared a list of local firms using CAD/CAM techniques who might be willing to assist. These included manufacturing companies such as Joseph Lucas Ltd. and a local firm specialising in the use, design and marketing of CAD/CAM systems: Deltacam Ltd.
- We liaised with the firms and arranged a programme of visits and short-term staff placements. Placement was for upwards of one week either for a continuous period or at regular intervals.

This process was part of the general Polytechnic Staff Development Programme which was designed to improve staff awareness in all departments of the polytechnic. Various levels of IT expertise were defined and departments were required to submit a training schedule showing their target profile of expertise. They were asked, as a matter of urgency, to attain the necessary level over the next two years. This procedure is certainly not unique and there may be better ways of solving the problem of staff training, but it has certainly been successful.

APPENDIX A: A CAD CURRICULUM

Introduction

As has been emphasised in previous sections, there is currently a vigorous move towards the combination of many of the sub-systems in commercial concerns into an integrated whole. For instance, in an industrial environment, it is desirable that CAD should be coupled strongly with CAM. Courses should reflect this and appropriate subjects should be cross-linked with others. Of course, this is nothing new; it has long been recognised that the material in one subject is often useful for reinforcing material in another. The process, however, is especially important in courses involving newer technologies because students must be encouraged to consider the whole design and production process in a holistic way.

It seems likely that future users of computers in the workplace must be responsive to rapid changes in the systems that they use—the so-called 'quantum leaps' in system development. It should be a major aim of all courses involving newer technologies that a 'system wisdom' should be inculcated so that our students will have the necessary competence to use systems in a flexible, confident and creative way. A good source of illustrative material and advice on these and other aspects of course design may be found in the BTEC publication *Common Skills and Core Themes* (September 1986).

Curriculum

Previous sections have dealt with mechanical engineering, electrical/electronic engineering, construction engineering and industrial design applications of CAD. It may be noticed that each of the contributors has a slightly different perception of the functions and character of CAD. This is because of the disparate nature of the designer's tasks in each of the fields; for instance, it is unlikely that solid modellers might ever play any significant part in electronic design; in mechanical engineering design, they are likely to be of fundamental significance in future systems. This makes it impossible to produce a detailed generic syllabus. The following is an attempt to provide a curriculum with common aims and principal objectives; these are largely process-based. Indicative content or objectives must be appended to suit the particular discipline involved.

Aims:

- to develop an understanding of the ways that computers may be used to aid and augment the design process
- to attain a working knowledge of the hardware and software components of a CAD system

- to attain the technical and personal skills necessary for the effective use of CAD systems
- to provide an appreciation of the place of CAD in the Integrated Business System
- to make a contribution to the general systems awareness necessary for the modern technician

Prinicpal objectives The nature of CAD systems:

- review the various types of systems architecture including single-user dedicated systems, centralised multi-user systems and networked systems
- identify the functions and purposes of the components of a CAD system
- examine the role of CAD in an integrated manufacturing system
- analyse the benefits in productivity increase, convenience, closer management control and organisational efficiency resulting from the use of CAD

CAD hardware considerations:

- obtain data from various sources and compare the functions, cost and performance of CAD hardware elements
- study, in detail, the properties of a range of devices commonly used in industrial applications of CAD

CAD software considerations:

- distinguish the software sub-systems which may be used in a relevant and typical CAD system
- use CAD systems to perform a variety of design tasks
- appreciate the organisation, structure and function of engineering databases and their use in CAD
- review current progress in the development of data exchange systems and intercommunication mechanisms

CAD management considerations:

- view, as a group, a selection of typical installations, taking particular note of their day-to-day running, organisation and layout
- investigate financial aspects of CAD systems including purchase, leasing, software/hardware maintenance and running costs
- appreciate the requirements of a system for the archiving, issue and control of design documents
- determine the factors to be considered in the effective selection of a system
- participate, as a group, in a role play of a task group performing a feasibility study for a modest installation, selecting a system and producing a recommendation for senior management

CAD human considerations:

- appreciate the way in which humans relate to computers and identify the properties of a well-designed human/machine interface
- examine the effect of CAD on the role of the designer
- understand the implications of the use of expert systems in CAD
- appreciate the economic, social and psychological effects of computers in general and CAE in particular

Indicative objectives and/or content

These will vary according to the field of study. There will, of course, be some degree of commonality but even in the more general sections of the curriculum, the material will probably be given different emphases.

APPENDIX B: PURVEYORS OF CAD EQUIPMENT AND SOFTWARE

The list which follows gives the source of most of the CAD hardware and software which is mentioned in the main sections of the paper. It is not intended that the list should be a guide to excellence; inclusion of an item just means that the contributor who mentioned it has had experience with it and has found is satisfactory.

Amplex Services Ltd. Sidehill Pilgrims Way Kemsing Sevenoaks Kent TN15 6XA 0732-61359/62670	STRESS
Apollo Computer (UK) Ltd. Balborne House Gossoms End Berkhamstead Herts. HP4 3LP 04427-75026	Workstations
Autodesk Ltd. 47 The Cut London SE1 8LL 01-928 7838	AUTOCAD
CAE Advisory Centre for FE Mech and Prod Eng Dept Birmingham Polytechnic Birmingham B42 2SU 021-356 6911	FINITE ELEMENT ANALYSIS STRUCTURES RIGID COUPLINGS
Cimtel Ltd. Aston Science Park Love Lane Birmingham B7 4BJ 021-359 0981	DRAWING OFFICE ADMINSTRATION CODING AND CLASSIFICATION
Control Data Ltd. 179-199 Shaftesbury Avenue London WC2H 8AR 01-240 3400	STRUPAK

Daisy Systems Corporation Berk House Basing View Basingstoke Hants. RG21 2HQ 0344-481888	Workstations LOGICIAN
Deltacam Systems Ltd. Aston Science Park Aston Triangle Birmingham B7 4AP 021-359 3659	BOXER DOGS DUCT
Design Computing Ltd. 2nd Floor Clifton Heights Triangle West Clifton Bristol BS8 1EJ 0272-292615	GINGA
Digital Dynamics Ltd. 17 Victoria Avenue Harrogate North Yorks. HG1 5RD 0423-60322	BOM
Digital Equipment Corp. Digital Park Box 110 Imperial Way Worton Grange Reading Berks. RG2 0TR 0734-868711	Computer systems
Gable CAD Systems Ltd. Arts Tower Western Bank Sheffield S10 2TP 0742-700696	GABLE
Genrad Ltd. Norreys Drive Maidenhead Berks. 0628-39181	HILO 3

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GMW Computers Ltd. Castle Mill Lower Kings Road Berkhamstead Herts. HP4 2AD 04427-5481	RUCAPS
IBM (UK) Ltd. Graphics Marketing Support Group PO Box 31 Birmingham Road Warwick CV34 5JL 0926-32525	Computer systems Workstations
Lattice Logic Ltd. 9 Wemyss Place Edinburgh EH3 6DH 031-225 3434	MODEL, SWITCHSMITH DRAFTSMITH, CHIPSMITH
McDonnell Douglas IS Ltd. Meirion House Guildford Road Woking Surrey GU22 7QH 04862-26761	ARC
Mentor Graphics (UK) Ltd. Mentor House Spencers Wood Reading Berks. RG7 1SS 0734-884888	Workstations
Pafec Ltd. Strelley Hall Main St. Strelley Nottingham NG8 6PE 0602-292291	DOGS BOXER
Prime Computer (UK) Ltd. Hounslow Centre 2-4 Lampton Road Hounslow Middlesex TW3 1JW 01-572 7400	SAMMIE
Qudos Ltd. Cambridge Science Park Milton Road Cambridge CB4 4BH 0223-862333	QUDOS

Racal-Redac Ltd. Newtown Tewkesbury Glos. GL20 8HE 0684-294161	ISIS
RM JM IT 42/46 Weymouth St. London W1A 2BG 01-486 4222	CAPITOL
Sandwell College of F/HE Open Tech Project in CAE Pound Road Oldbury Warley Sandwell West Midlands B68 8NA 021-544 7446	Various Open Tech units
Silicon Microsystems Gastons Road Malmesbury Wilts. SN16 0BE 06662-4844	Cell-based libraries
Silvar-Lisco Ltd. Alpha House London Road Bracknell Berkshire RG12 2TH 0344-481888	Full custom design
Sun Ltd. Sun House Pembroke Broadway Camberley Surrey GU15 3XD 0276-62111	Workstations
Superdraft Systems Atlantic St. Broadheath Altrincham Cheshire WA14 5DD 061-941 2327	SUPERDRAFT
Tektronix (UK) Ltd. Forth Avenue Globe Park Marlow Bucks. SL7 1YD 06284-6000	Graphics displays

The Trueview Project Three Spires House 16A Bird St. Lichfield Staffs. WS13 6PR 05432-51151	SKETCH-IN-DEPTH SITE SURVEY
Whitechapel Computer Works Ltd. 75 Whitechapel Road London E1 1DU 01-377 8680	Workstations

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Objectives

The objects for which The Further Education Unit (FEU) is established are to promote, encourage and develop the efficient provision of further education in the United Kingdom and for that purpose:

a) to review and evaluate the range of existing further education curricula and programmes and to identify overlap, duplication, deficiencies and inconsistencies therein;

b) to determine priorities for action to improve the provision of further education and to make recommendations as to how such improvement can be effected;

c) to carry out studies in further education and to support investigations of and experimentation in, and the development of, further education curricula and to contribute to and assist in the evaluation of initiatives in further education;

d) to disseminate and publish information, and to assist in the dissemination and publication of information, about recommendations for and experiments and developments in further education.